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DEVELOPMENT AND SIGNIFICANCE OF THE GREAT SOIL GROUPS OF THE UNITED STATES

By

CHARLES E. KELLOGG
Principal Soil Scientist, Division of Soil Survey
Bureau of Chemistry and Soils

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CONTENTS

INTRODUCTION

It is the purpose of this publication to summarize the recent knowledge regarding the formation and significance of the great soil groups of the United States for the general reader. The treatment is in no sense complete or exhaustive. Attention is directed toward a discussion of those principles of broad implication. Should the reader require more specificity, the detailed reports of surveys and researches must be consulted.

The nature of soils and the environmental factors responsible for their genesis are briefly discussed. Illustrations are included of each of the great groups of soils, and their particular evolution is explained. The practical implications of a knowledge of the great soil regions and their relationship to the biological complex, and consequently to human institutions, are pointed out. Within these large soil groups, developed in association with their characteristic vegetation and under the dominating influence of climate and vegetation, are important variations in soils due to the influence of local

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factors. Examples of such local variations are shown and their relationship to the general group discussed as to the genesis of the soils and the local adaptation of agriculture within the general region.

Although soil science, as a well-defined branch of knowledge, is of comparatively recent inception, the development of a distinctive nomenclature and line of interest has been rapid. Any summary statement of a rapidly developing body of knowledge is destined to be somewhat immature and soon out of date. Yet, even at the risk of subsequent corrections, it seems advisable to summarize the general bases of the modern concept of soils, together with those basic facts regarding soil genesis, which are well established and upon which there is some general agreement.

Before about 1870, in Russia, and up to a later date in western Europe and North America, studies of soils were more or less incidental in several fields of science, including geology, chemistry, and botany. Students of plant nutrition and agronomy were forced to make certain assumptions regarding soil, but these studies were not conducted in such a way as to give any basic knowledge regarding the fundamental nature of soil and its development. Geology early became an established discipline with distinctive field methods for the study of rock formations, including those on the surface of the earth. Inasmuch as soils occurred on the surface of the earth and were developed, in part, from the products of weathering geological formations, it is not surprising that geologists took some interest in the subject.

Many of these early studies of soil from the geological point of view were fruitful, provided comparisons were confined within small areas in which conditions of climate, native vegetation, relief, and age were essentially uniform. But without definite knowledge of the soil characteristics as such, even these results were difficult to interpret in terms of native or cultural plants. The confusion, as may be seen from what follows, came about by assuming that a direct relationship exists between the nature of rocks and of the soil that develops from their weathered products; whereas many other factors, especially constructional biological forces, more frequently dominate the situation in soil development.

Furthermore, the older concept of soil as a static body is wholly inadequate. In accordance with such a concept early students of plant nutrition looked upon the soil as a more or less static " storage bin " of plant nutrients. By analyses of the soils and the plants they produced, it was thought that a balance sheet could be drawn up, indicating the " needs " of each soil and prophesying its productivity and longevity. Such prophecies usually missed, owing to the failure to appreciate the dynamic character of soil and the natural provisions for continued development and renewal. It is teeming with micro-organisms of great importance and of great variation from one soil to another. It is in continual process of change and development.

Beginning about 1870 in Russia and somewhat later in western Europe and North America, it was observed that certain groups of soils were confined to rather distinctive climatic and biological regions, whereas geological deposits are distributed quite promiscu-
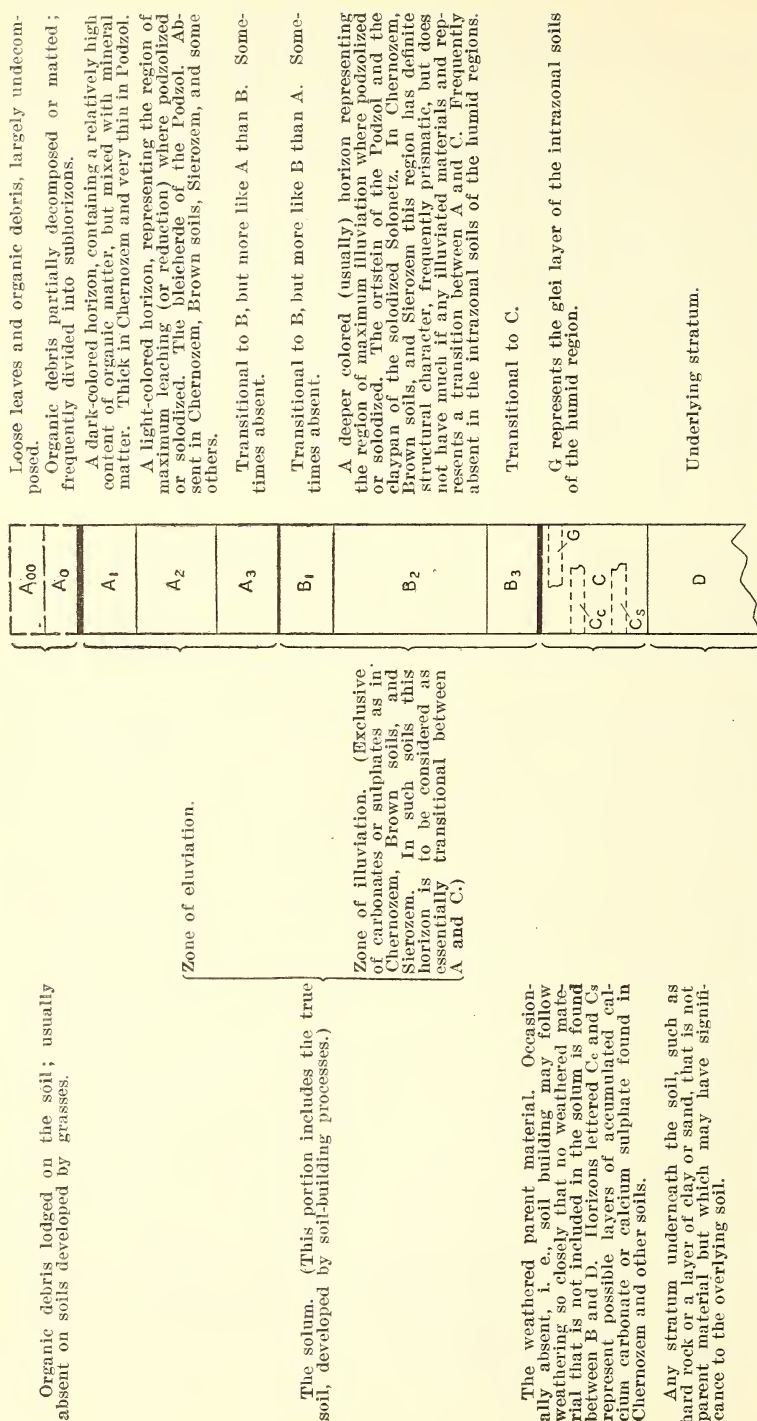
ously over the world. Excavations in these soils, exposing a section of the soil, showed that they were made up of a series of layers, or horizons, called, collectively, the soil profile. These layers frequently vary enormously in physical and chemical properties; yet, unlike the layers in a body of sediments, a genetic relationship exists between them. Such layers in normal soils are the products of soil-forming processes impinged upon the material produced through weathering.

With the recognition that each soil has a definite morphology as well as a distinct geography came the logical conception of soil as an independent natural body. Naturalists then began to study the soil from an entirely scientific point of view and to accumulate a body of knowledge bearing upon this line of interest. Thus, about 1870, a new discipline arose—pedology. The fundamental principles elucidated by this science are, of course, those upon which the applied phases of soil science (agrology) rest; but their study and formulation are not wholly dependent on possible future application.

THE NATURE OF SOIL

Before proceeding to a discussion of the character of actual soils and their classification, some general remarks concerning the nature of soil must be made. It has been mentioned that the soil is made up of several horizons, called, collectively, the soil profile. These horizons vary tremendously in different soils; many that are strongly developed in some soils are only weakly developed in others. Figure 1 illustrates the general, or hypothetical, soil profile. Like the "hypothetical plant" used by botanists to illustrate possible forms, no such entity exists in nature but it serves to illustrate nearly all of the possible layers. No one soil may have all these horizons well developed, but every soil has at least a part of them. Some pictures of actual soil profiles are shown in plate 1.

The principal horizons of the soil profile are A, B, and C. Taken together, the A and B horizons are referred to as the solum which represents the true soil produced by the soil-building processes. The designation C refers to the weathered parent material or unconsolidated rock directly under the solum and from which the solum is usually developed. Originally, the A horizon was considered to include the upper part of the solum, in which accumulation of organic matter and bases was taking place through the direct influence of plants, as in the surface horizon of the Chernozem, and the B horizon included the lower part of the solum, transitional between the more or less uniformly developed surface A horizon and the parent material, unaltered by soil-building processes. The study of soils was later extended to include those having a leached layer in the upper part of the solum and a horizon of colloid accumulation in the lower part, and as the A is now defined it may include a horizon (fig. 1, A_2) impoverished of colloids and bases through such soil-building processes as podzolization or solodization; and the B horizon in such soils is particularly characterized by a deeper color than that in A_2 and by a high content of colloid.

Grouping	Horizon	Description
Organic debris lodged on the soil; usually absent on soils developed by grasses.	A_{00}	Loose leaves and organic debris, largely undecomposed.
	A_0	Organic debris partially decomposed or matted; frequently divided into subhorizons.
The solum. (This portion includes the true soil, developed by soil-building processes.)	A_1	A dark-colored horizon, containing a relatively high content of organic matter, but mixed with mineral matter. Thick in Chernozem and very thin in Podzol.
Zone of eluviation.	A_2	A light-colored horizon, representing the region of maximum leaching (or reduction) where podzolized or solodized. The bleicherde of the Podzol. Absent in Chernozem, Brown soils, Sierozem, and some others.
	A_3	Transitional to B, but more like A than B. Sometimes absent.
Zone of illuviation. (Exclusive of carbonates or sulphates as in Chernozem, Brown soils, and Sierozem. In such soils this horizon is to be considered as essentially transitional between A and C.)	B_1	Transitional to B, but more like B than A. Sometimes absent.
	B_2	A deeper colored (usually) horizon representing the region of maximum illuviation where podzolized or solodized. The ortstein of the Podzol and the claypan of the solodized Solonetz. In Chernozem, Brown soils, and Sierozem this region has definite structural character, frequently prismatic, but does not have much if any illuviated materials and represents a transition between A and C. Frequently absent in the intrazonal soils of the humid regions.
	B_3	Transitional to C.
The weathered parent material. Occasionally absent, i. e., soil building may follow weathering so closely that no weathered material that is not included in the solum is found between B and D. Horizons lettered C_c and C_s represent possible layers of accumulated calcium carbonate or calcium sulphate found in Chernozem and other soils.	C_c C C_s G	G represents the glei layer of the intrazonal soils of the humid region.
Any stratum underneath the soil, such as hard rock or a layer of clay or sand, that is not parent material but which may have significance to the overlying soil.	D	Underlying stratum.

NOTE.—Important subdivisions of the main horizons are conveniently indicated by extra numerals, thus: A_{21} and A_{22} represent subhorizons within A_2. No one soil would be expected to have all these horizons well developed, but

FIGURE 1.—A hypothetical soil profile having all the principal horizons. No one soil has some of them. It will be noted that horizon B may or may not have an accumulation of clay. Horizons lettered C_c and G may, and usually do, appear between B_3 and C.

SOIL COLOR

Each soil horizon has a distinctive color, texture, and structure. The possible colors that these various horizons may exhibit can be seen from an examination of plate 10 showing the representative profiles of the great soil groups. Certain additional colors may be found locally as an inheritance from the parent rock.

Although color in itself may be of minor importance it is frequently a significant criterion of other soil conditions of extreme importance. The content of organic matter in soil is such a characteristic, and its presence is, to a considerable extent, evidenced by the color of the soil. Other factors being constant, soil colors may range from white, through the browns, to black, as the content of organic matter increases. The most stable portion of the decomposed organic matter, humus, is darker than the raw, or less well decomposed, plant remains. Raw woody peat is brown, whereas the well-developed organic soil produced from such material is black or nearly so. As organic matter is not the only coloring matter in soils, color, by itself, is not an exact measure of the content of this important constituent; and beyond a black color further variations in content do not, of course, give rise to differences in color.

The red and reddish-brown colors of soils are greatly dependent upon the content of oxidized, unhydrated iron oxide (hematite); while the oxidized, hydrated iron (limonite) is yellow or yellowish brown. Compounds containing reduced iron may impart a pale bluish color to the soil. Where such compounds exist as coatings around the other soil grains a relatively small content of the compound may have a great influence on the color of the soil mass. These various colors of the iron compounds are important as they afford significant indicators of the aeration and drainage of the soil. Red colors indicate, in general, good oxidation and good drainage; whereas grayish blue indicates poor drainage. Imperfectly drained soils are frequently mottled with gray, yellow, and rusty brown at some depth beneath the surface. Well-drained soils may sometimes exhibit a yellow color as an inheritance of a previous condition of poor drainage.

Various colors or shades of color may be imparted to the soil as a result of special conditions, such as the purple colors sometimes attributed to a high content of manganese, or the white crusts or horizons indicating a concentration of salts. In very young soils especially, colors may be inherited from those of the rock. These variations in color frequently indicate chemical and mineralogical differences of great importance in the growth of native and cultural plants. It is quite obvious that color by itself cannot be used as a criterion in soil classification, but when considered in connection with other characteristics of the soil it is of extreme importance in the classification.

SOIL TEXTURE

The texture of soils refers to the size of the individual grains or particles. This property is partly inherited from the parent material from which the soil may have been developed and is partly a result of soil-forming processes. The B horizon of the soils developed under podzolization, for example, is usually higher in clay content than

the other soil horizons. These soil particles are grouped, according to size, under three principal heads—sand, silt, and clay. As a soil is rarely, if ever, composed entirely of any one of these separates, on the basis of the relative percentages of these, soil class is recognized. The principal classes of soil according to texture are sand, loamy sand, sandy loam, loam, silt loam, clay loam, silty clay loam, and clay, in increasing order of their content of the fine separates. The physical properties of soil vary greatly with differences in texture. As the greater part of the physical and chemical properties of soil and changes in the soil are attributed to forces and reactions occurring at the surface of the soil grains, it is clear that the fine clay portion will be the most important, inasmuch as the surface exposed per unit weight of soil increases enormously as the diameter of the individual grains decreases. Some of the important properties of this fine material will be considered briefly under a discussion of soil colloids.

SOIL STRUCTURE

As a characterization of the mechanical structure of the soil in addition to texture, soil structure, which refers to the manner in which the individual grains are arranged, is even more important. The individual grains may be grouped together in any one of a great number of forms, according to the texture of the soil, the chemical nature of the fine clay portion, the aeration, the kinds of plants and other organisms growing in the soil, and similar factors. The soil grains may be grouped into plates, crumbs, granules, prisms, or other characteristic morphological structural units. A few of the more common forms of soil structure are shown in plate 2. These forms may vary considerably themselves as to hardness and plasticity under different degrees of moistening.

As each genetic horizon of a soil profile has its characteristic structure, this morphological feature is very important in soil classification. Not only is structure highly significant in scientific studies of the soil itself but it is of great direct importance in determining the soil's receptibility to plant roots, its amenability to cultivation, and its susceptibility to blowing by the wind or erosion by water. For example, during periods of drought, barren soils, even those containing large amounts of clay, may blow badly if the grains are grouped into fine crumbs or granules. On sloping land more care is required to prevent erosion by water if the B horizon of the soil has a massive structure, relatively impermeable to water, as compared to a soil having a crumb or nut structure permeable to water in the B horizon.

SOIL COLLOIDS

The finer portion of the soil particles, both organic and inorganic, are colloidal in nature. The relative amounts and nature of these colloids in the various horizons of the soil profile determine, more than anything else, the fundamental character of the soil. The inorganic colloids themselves are complex alumino-silicates resulting largely from the partial weathering of feldspars and other primary minerals. The organic colloids consist of materials resultant from the decomposition of organic matter. Although these colloids do not

themselves enter the plant roots they do have a tremendous influence on the ability of the soil to retain plant nutrients and water and to furnish these to growing plants. This colloidal material has been aptly designated as the " protoplasm of the soil."

Colloidal material is tremendously complex, and much remains to be discovered about its properties and development under different regimes of soil development. Certain useful generalizations can be made, however, regarding its behavior under the principal processes of soil genesis. These soil colloids hold cations (i. e., ions having a positive charge, such as the calcium ion, hydrogen ion, and sodium ion) by the ordinary base-exchange reaction. Especially in accordance with the relative amounts of the various cations in the soil solution, these ions will be held by the colloids. The nature of the parent material, the drainage, the amount of water percolating through the soil, and especially the character of the growing vegetation and of the decomposing organic matter, will determine which ions will be held by the colloids. The properties of the colloids, and consequently the character of the soil, vary enormously, depending upon which cations are dominant in the colloidal adsorbing complex. There are three general types of soil colloids, designated as the hydrogen colloid, the sodium colloid, and the calcium colloid. In Nature the colloids are never completely of one type; and less common ions frequently make up a considerable portion of the total exchangeable bases.

In the presence of considerable quantities of salts, all these colloids are flocculated and immobile. In the absence of flocculating electrolytes, the hydrogen colloid is acid and rather easily dispersed into colloidal suspension, the sodium colloid is highly alkaline and is most easily dispersed, and the calcium colloid is mildly alkaline and tends to remain in a flocculated state. Thus the hydrogen and sodium colloids can be easily leached from the surface soil by percolating waters, whereas the calcium colloid cannot. Under conditions favorable for the mobility of the colloids, the surface horizons may become almost impoverished of the finer clay, as in the case of the whitish upper horizons of certain soils. These mobile colloids may be entirely removed from the soil or they may be deposited at some lower level, giving rise to a more dense layer, frequently dark in color, characteristic of many soils.

THE CLASSIFICATION OF SOILS

The classification of soils, like that of any other natural bodies having distinctive characteristics, is based upon their inherent characteristics. Before the development of the modern concept of soils, and consequently before there had been accumulated any body of soil science, classificational schemes were made on the basis of the nature of the parent material (geological) or upon some other environmental factor. Of these schemes, the one advanced by the Russians, based largely on the climate, was by far the best. In Russia the vegetation closely followed the climatic changes, and rather sharp boundaries between plant associations, soil types, and climatic regimes obtained contiguously. In other countries, such as the United States, although a classification on the basis of climate might be superior from some points of view to any on a geological basis, it

is still inadequate. For one thing the types of vegetation are not so sharply coincident with climatic changes. Although not of first importance in determining the general nature of broad soil zones, differences in the underlying rock and in relief are commonly of first importance in determining local soil differences. The abandonment of these schemes for the development of a strictly scientific classification based on the character of the soils themselves was the natural outcome as the science developed.

The purpose of classification is to place the objects to be classified into suitable categories, the better to study and remember their characteristics and to interpret their interrelationships. According to this statement of the problem, schemes for the classification of natural bodies, such as plants and animals, have been worked out; and on the same logical basis the classification of soils has been recently developed.

Average profiles of the great soil groups are illustrated in plate 10. The general distribution of the important groups of these in the United States is shown on page 31 (fig. 4). The illustrations of the zonal soils represent the average conditions to which the soils of a large area are all related. The intrazonal types are those found under some special condition which may be wide-spread, especially poor drainage. The average, or normal, profiles are those developed under average conditions of parent material. Local variations in climate, relief, vegetation, and age, and extremes in parent material, naturally may be expected to give rise to soils of different character. Thus, around each of the zonal and intrazonal average profiles there are grouped a large number of profiles, all having the same very general characteristics but varying greatly in details. These variations are commonly of great significance in any detailed consideration of the soil and are usually the only ones to be observed within a small area.

In the field mapping of soils the units described and shown on the map are established on the basis of the characteristics of the soils themselves. Any one of the great zonal soil groups illustrated in plate 10 may include several hundred of these units varying in details of morphology just as the order Araneida (spiders) includes animals having the same general morphology but with many species varying in the details of this general character.

The most important of these field units is the soil series which includes those soils having the same differentiating characteristics. The soils included in a series have essentially the same color, depth, and structure of the horizons of the profile. They have the same drainage and approximately the same relief and conditions of parent material. The texture of the upper part of the solum (A) may vary. These series are given geographic names taken from the location in which they were first found. Norfolk, Hagerstown, Barnes, Miami, Houston, and Mohave are names of important soil series. Within the soil series are soil types, defined according to the texture of the upper part of the solum. Thus the class name of the soil texture, such as silt loam, loam, or clay loam, is added to the series name to give the complete name of the soil type; for example, Miami loam, Miami silt loam, and Miami clay loam are types within the series Miami. With the exception of the texture of the surface soil, these soil types have the same differentiating characteristics.
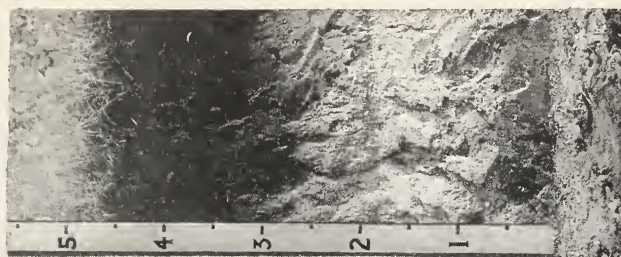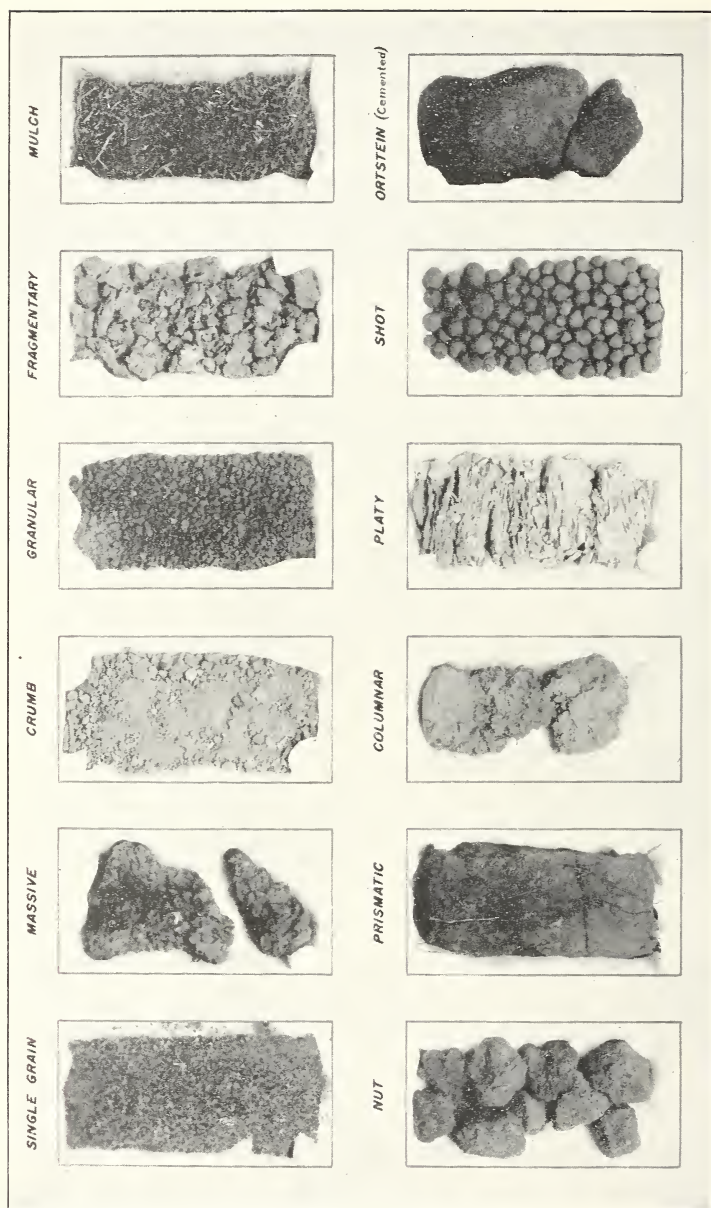
PLATE 1
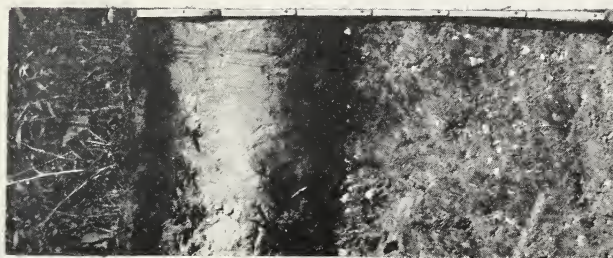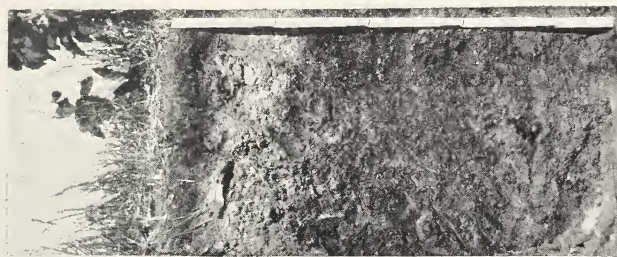
PODZOL PODZOL SOLOTH CHERNOZEM

Four soil profiles. A Podzol shown at the extreme left has a thick covering of forest duff, underlain abruptly by a whitish A_2 horizon. The other Podzol soil has lost much of the surface duff through burning; in this picture a dark brown ortstein immediately under the white leached horizon stands out distinctly.

PLATE 2

Several important types of soil structure. All of these structural types are produced through the operation of soil-building processes, except that the single grain, fragmentary, and massive may be developed or may be inherited from the parent material. The structure of soils is of great importance in studying their genesis or ecological relationships. (About one-fourth actual size.)
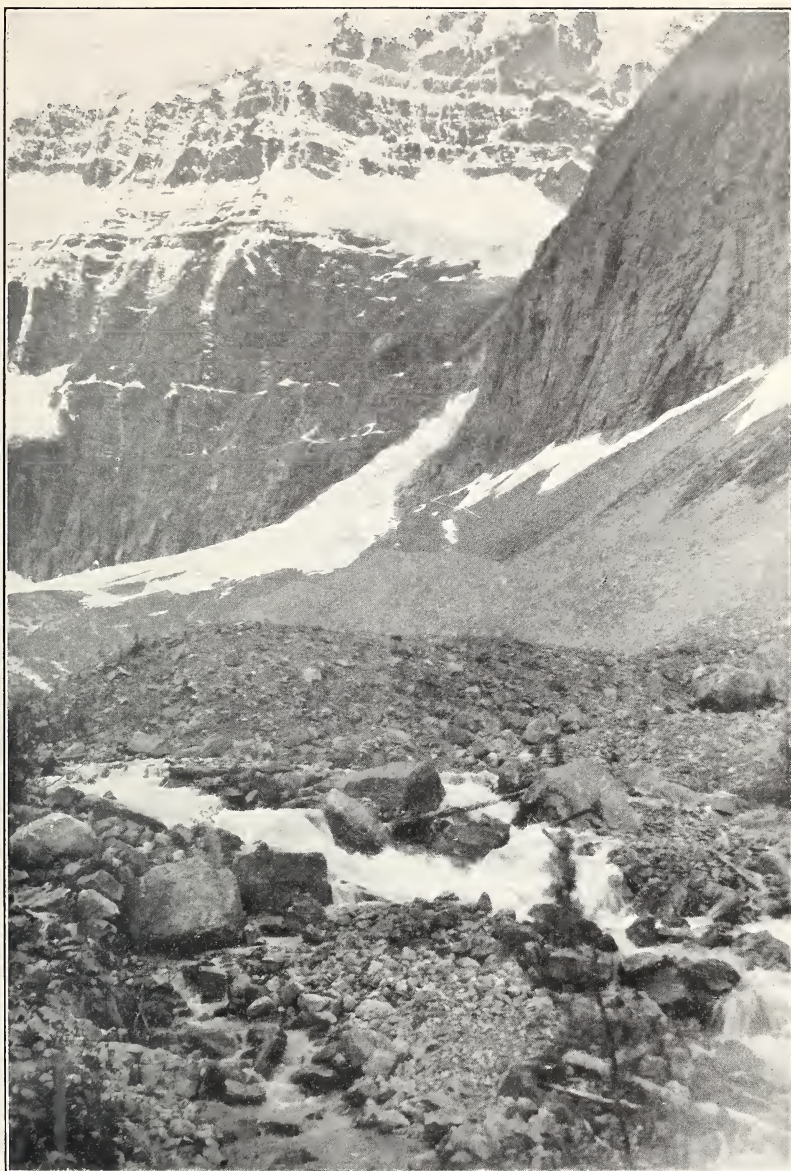
An example of land without soil. Here weathering is active, but there is very little life and consequently very little soil. The destructional weathering activities will in time produce a parent material from which soil may be formed by the constructional processes of soil development.

PLATE 4
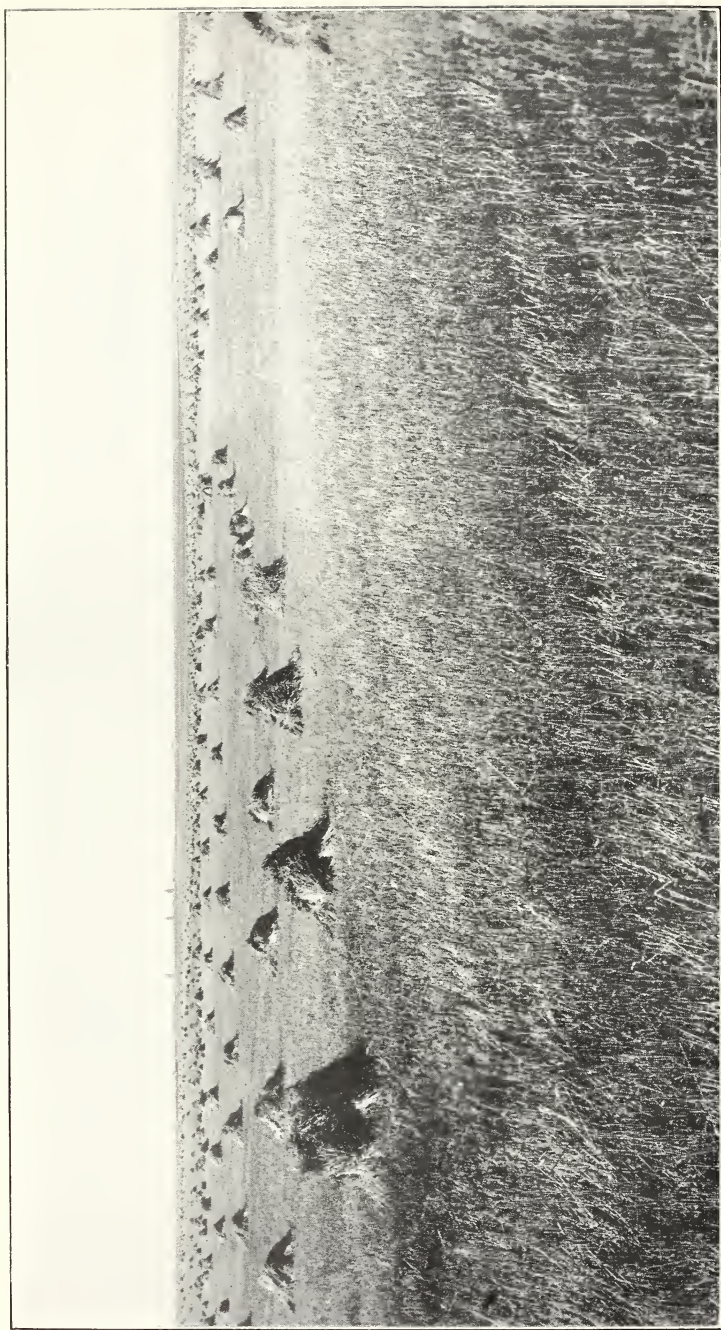
A view of Chernozem. These black, fertile soils are especially suited to the production of cereals in large units. The subhumid climate is somewhat hazardous and sharply limits the production of many kinds of subsistence crops.

A phase of a soil type is occasionally recognized for the separation of soils within the type which differ in some minor characteristic that may have special practical significance. Such a category is analogous to the term " strain " as used with plants. Differences in relief and stoniness are frequently shown as phases. Such differences in relief may not materially influence the soil character, but may be of great significance in land use, especially where cultivated.

On the average soil map of a county, ranging from 500 to 600 square miles in area, from 15 to 60 of these soil units may be recognized and mapped. Each of these is established on the basis of the characteristics of the soil itself, except that phases may be separated on the basis of relief or stoniness, physical characteristics of the land which are not strictly soil features but are important in determining the use of the soil. The experience of people using these types of soil for various purposes, together with the results of experimental work, when classified according to soil types, makes a complete picture of the physical potentialities of the land for use. A small portion of such a detailed soil map is shown in plate 11. The detailed soil map is accompanied by a comprehensive report describing the soil units shown on the map and explaining their use.

Before describing the mapping units in more detail the broad groups of soils and their genesis need to be examined, after which the variations within a group will be discussed. [1] These soil series are further grouped into progressively more inclusive units according to important differentiating characteristics. The technical details of such a comprehensive scheme of classification are set forth by Marbut. [3] Attention here will be devoted particularly to the great soil groups of Marbut's category 4 and to the important intrazonal groups of his category 3.

THE FACTORS OF SOIL GENESIS

The principle of geographics, associated with the modern concept of the soil as a dynamic natural body in equilibrium with its environment, leads to several important deductions regarding the forces in operation during the genesis of a soil. In general, there are two, not mutually exclusive, sorts of activities: (1) Destructional activities of weathering, physical and chemical, and (2) constructional biological forces. Although pedology is especially concerned with the latter, the importance of the former cannot be neglected. As a graphic illustration of those factors of the landscape most prominently associated with and responsible for the development of soil the following can be written:

$$Soil = f \text{ (climate, vegetation, relief, age, parent rock)}$$

[1] For further information regarding these units and their significance in land use the reader is referred to the published soil survey reports. The Division of Soil Survey of the U. S. Department of Agriculture has published approximately 1,500 soil maps and reports during its operation over a period of years. Technical Bulletin 469 [2] explains the details of land classification made, in part, from such maps. The Illinois Agricultural Experiment Station and some other agencies have also published soil maps and reports.
[2] KELLOGG, C. E., and ABLEITER, J, K. A METHOD OF RURAL LAND CLASSIFICATION. U. S. Dept. Agr. Tech. Bull. 469, 30 pp., illus. 1935.
[3] MARBUT, C. F. SOILS OF THE UNITED STATES. In Atlas of American Agriculture, pt. 3, Advance Sheets no. 8, 98 pp., illus. 1935.

Of these the first two, climate and vegetation, are of the greatest importance in determining the nature of the zonal groups illustrated in plate 10. The other three, however, are important in determining the intrazonal types and in producing important subdivisions within the zonal groups.

The chief components of climate, rainfall, temperature, and humidity will obviously influence the amounts of various chemical elements and compounds in the soil. These factors will be reflected in the soil directly and especially indirectly through their influence upon vegetation and upon the weathering processes which produce the parent material from which soil is developed. Local conditions of relief, and the vegetation itself, will serve to modify the climatic conditions which prevail within and at the immediate surface of the soil. Also the cooling and moistening at the surface is influenced somewhat by the nature of the underlying rocks. Inasmuch as extremes in chemical nature or texture of the parent material may influence the nature of the salts in the soil and the texture of the soil, the mechanical and chemical composition of the underlying rocks is of significance. As the whole process of soil genesis is one of evolution, together with the development of the entire landscape, of which it is a part, age (in a relative sense) is important.

THE DEVELOPMENT OF PARENT MATERIAL

The parent material from which the soils are produced is largely accumulated through the processes of weathering. Weathering includes those chemical and physical processes by which rocks are broken down into unconsolidated materials. These processes are mainly destructional and are essentially sterile (pl. 3). Although some of the reactions and processes included under weathering may also be taking place in the soil, here they are merged with other processes of greater magnitude and importance. The development of soil should not be confused with the weathering of rocks. By weathering, parent material for soil may be produced, but any one of a vast number of greatly different soils may be produced from identical parent materials. The parent rock is a passive element, rather than an active force in soil formation. Examples of all the zonal and intrazonal groups of soil shown in plate 10, except the Rendzina, could easily have been developed from identical parent rock. Nevertheless, it must not be overlooked that important variations in soils, due to characteristics inherited from the parent material exist, and are responsible for subdivisions within the groups. In mountainous areas, for example, the extreme nature of the local situation may almost, if not entirely, prevent soil development.

Wind, moving water, ice, and temperature changes are important factors in the disintegration of masses of rock. Unconsolidated material is frequently transported to form deposits of weathered material from which various soils may be produced depending on the environment. For example, deposits of dune sand and loess are built by the wind, alluvial fans and flood plains by water, and numerous glacial formations by ice.

Under the chemical action of water, carbonic acid and oxidation-reduction reactions, the chemical nature of the original minerals is

altered. These chemical reactions during weathering are somewhat similar under different climatic regimes, but external differences of moistening, and especially of temperature, determine the direction and rate of the reactions. The greater part of the mineral matter in rocks is composed of silicates and alumino-silicates, together with varying quantities of other inorganic compounds. Under the action of weathering these may be hydrolized. By various interreactions elements may be recombined to form a great number of compounds, such as sodium chloride, sodium sulphate, magnesium carbonate, and a host of others. These may accumulate in the soil or be leached in various proportions, depending on the degree of moistening and the position of the water table. It is probably safe to say that the climate has a greater direct influence on weathering than on soil formation; although the indirect effect of climate on soils through its influence on the biological complex is of the utmost importance.

LIVING MATTER

Some time after or continuous with the accumulation of parent material there is the introduction of living matter which is largely responsible for the constructional processes of soil development. This living matter presents two different aspects: (1) Synthesis and (2) decomposition. There are two general groups of plants which synthesize organic matter—grasses and trees. Differences of great significance exist between plants within each group, especially as regards their feeding habits and the relative proportion and absolute amounts of the various elements taken up by the roots and deposited in or on the upper part of the solum.

The concentration of the various bases such as sodium and calcium in the water percolating through the solum, depends to a considerable extent on the amounts of these in the plants. The amount in the plants depends partly on the nature of the plants and partly on the quantities of these materials in the lower part of the soil available to the plant roots. For example, organic remains under the pine forests have a much lower content of bases than those under the beech-maple forest. Some variation obtains, however, within each type of forest. Ordinarily the beech-maple forest finds its best site in areas having a good supply of bases in the soil and parent material, and under such usual conditions the leaves are relatively high in bases, especially calcium; but if the other conditions affecting growth are favorable, such as humidity, water supply, and temperature, this type of forest may thrive where bases are scarce and under such conditions will furnish the soil with organic matter relatively low in these ash constituents.

Grasses are, in general, strong feeders on calcium and return large amounts of this element to the surface soil. But the various species of grasses vary greatly in their total content of bases and in the relative proportion of the various elements. Certain species are very high in the sodium salts and thus favor the production of sodium colloids in the soil with far-reaching influences on soil morphology. These relationships between soil and plant are so interdependent that it is not always possible to point to one as causal. Thus a soil high in its content of sodium favors those plants naturally high in sodium; and the plants, in turn, tend to

maintain the soil, particularly the upper part, high in sodium, greatly influencing the development of the solum. As the type of vegetation slowly changes, the soil changes; or, more accurately, the soil and the plant association together move toward a new equilibrium.

Plants having the greater part of their roots in the surface soil tend to reduce the amount of leaching through the upper part of the solum as compared to more deeply rooted plants. From this point of view grasses would, in general, tend to restrict leaching by taking more moisture from the surface soil than trees and leaving less to percolate to the lower soil. The generally shallower rooting of conifers as compared to many hardwood trees may also be significant in reducing the percolation of water through the upper part of the soil under the former.

Of those organisms which decompose organic matter there are (1) the higher animals, (2) aerobic bacteria, (3) anaerobic bacteria, and (4) fungi. The optimum conditions for the growth of these organisms vary widely between classes. Furthermore, the different classes of micro-organisms which decompose organic matter give rise to different products. In cases where the processes go to completion, of course, the ultimate end products would be the same; namely, carbon dioxide, water, and ash. But the products actually found in the soil at any moment are largely intermediate compounds, and these vary greatly, depending on the organisms responsible for their presence. Such decomposition products produced by bacteria are, in general, relatively insoluble or stable as compared to those produced by fungi. Thus, conditions which favor the growth of fungi as compared to bacteria, may lead to less accumulation of organic matter in the soil. Further, the influences of the organic compounds produced by these different organisms upon the chemical nature and movement of the mineral colloids and compounds in the soil are at least partly responsible for great differences in soil morphology.

In general, bacteria are less tolerant of acidity in the soil than fungi. Several kinds of aerobic bacteria, of great importance in providing available forms of nitrogen to plants, do not thrive in acid soils. Such soils are, therefore, not naturally favorable to the growth of plants requiring considerable nitrate nitrogen, such as most ordinary crop plants. In many of these soils conditions are such that, by rather simple treatments, including the use of lime, this condition may be altered to one more favorable for crop production. Many disease organisms which attack plants are conditioned in their growth by the soil, either directly or indirectly through the influence of the soil on the physiological condition of the plant. Many such plant diseases are most economically and effectively controlled through soil treatment or, especially, through the proper selection of soil for the production of particular crops.

CLIMATE

The influence of climate in soil genesis is most profound. Attention has already been drawn to the influence of climate upon the development of parent material through weathering. Certain fundamental chemical reactions, conditioned by climatic factors, such as hydrolysis, hydration, carbonation, and oxidation, are common to

both weathering and soil-forming processes. Even after soil development has advanced to a considerable extent, there may be said to be continued weathering of some of the mineral particles within the soil. Variations in climate, especially variations in temperature, influence the speed of these reactions.

Of great importance to soil genesis is the amount of water actually percolating through the soil, and this amount will depend, in part, on the rainfall, temperature, relative humidity, and length of the frost-free period. The actual soil climate will also be conditioned by the slope of the land and the vegetative cover. With a given rainfall, the amount of water left free to percolate will be increased with an increase in relative humidity, with a decrease in temperature, and with an increase in the period during which the soil remains unfrozen.

The distribution of the rainfall is also a matter of importance. If the season of heaviest rainfall is coincident with the season of highest temperature, less leaching of the soil will take place as compared with a case where the period of highest rainfall is accompanied by a lower temperature above freezing. For the formation of most soils it is important that there be both moist and dry periods. It would seem, for example, that the Podzol soils, normally developed under a climatic regime giving rise to considerable leaching, do not develop unless there are dry periods during which the capillary movement of water in the soil is upward.

Differences in temperature below freezing are apparently not of great direct importance in soil genesis, that is, whether the average temperatures for the coldest months are 0° F. or −40° is not greatly important, except as they influence the native vegetation. In cold regions where the average annual temperature falls much below 26°, the deeper substratum remains permanently frozen.

As the values for average rainfall and temperature do not present a satisfactory description of climatic conditions, various sorts of expressions have been employed in order to give an accurate picture of the climate as a factor in soil formation. One of the most important of these has been the N–S quotient.[4] A system which is, perhaps, more satisfactory for the classification of climatic types has been recently devised by Thornthwaite[5] on the basis of what he calls " precipitation effectiveness " and " temperature efficiency " with added refinements, according to the periodicity of the rainfall and temperature. In general, the boundaries of his climatic types roughly parallel or coincide with those of many of the zonal groups of soils, although there are discrepancies. Possible future improvements in the treatment of climatic data, together with an increase in the number of stations and longer records, may allow a still closer fitting of climatic zones to soil zones. It is safe to venture, however, that such correlations will need to be kept on a very general basis and many exceptions allowed, since climate is only one of the factors concerned in soil development and its direct influence is not so pronounced as that of vegetation.

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[4] This factor is calculated as follows : The water-vapor pressure, in millimeters of mercury, for the average annual temperature is multiplied by the relative saturation of the air (100 − relative humidity) to obtain the absolute saturation deficiency of the air. The annual precipitation in millimeters is divided by this value to obtain the N–S quotient.

[5] THORNTHWAITE, C. THE CLIMATES OF NORTH AMERICA. Geogr. Rev. 21 : 633–655. illus. 1931.

The greatest influence of climate in soil genesis is exerted indirectly through its partial determination of the native vegetation under which the soil develops. Attention has already been directed to the great importance of living matter in the constructional processes of soil formation from weathered parent materials. Because of these facts, more than because of the direct influence, boundaries of climatic types roughly parallel those of the zonal groups of soils. Although climate is of tremendous importance in determining plant associations, it is not the only factor, and near their limits small but determining differences in climatic factors are difficult to analyze. The soil itself, greatly influenced by plants, in turn influences them: they evolve together.

One of the most important differences between the boundaries of climatic types and those of the zonal groups of soils is at the margin of the Prairie soils. Near the boundary between these soils and those of the Gray-Brown Podzolic group in the United States, for example, one may find an intimate mixture of the two contrasting soils in situations where there are no observable differences in climate, age, relief, or parent material; yet some factor, ordinarily of minor importance, was able to determine the balance between a forest vegetation and a grass vegetation, responsible for the great differences between the two groups of soils. Frequently one can find such differences ascribable to obvious differences in relief or parent rock, but in many other cases such differences do not exist and the determinant remains obscure.

The intrazonal groups of soils have a considerable range of climatic conditions. Although all the factors are important in the genesis of these soils, their dominating characteristics are the result of local factors, especially relief. Differences in climate are commonly responsible for variations within the groups. In general, however, there are three groups of intrazonal soils associated with each of the two general groups of zonal soils as shown in plate 10. One group, the Rendzina, is associated with several Pedocals as well as with the Pedalfers, and the Wiesenboden is not uncommonly found with Chernozem.

RELIEF

The examples of the zonal soils shown in plate 10 are only to be found on the undulating upland. Where the relief is less pronounced and drainage is poor, hydromorphic equivalents of the soils normal for the region may be developed in the humid regions; whereas in the arid regions the salty soils and their successors are to be found. Examples of such intrazonal soils are shown in plate 10.

It must be emphasized that the normal zonal soils are found on the undulating, but not flat or hilly, upland. Under such conditions, the drainage is good but not excessive, and there is a constant removal of some of the surface soil through erosion.[6] Thus gradually the profile is being renewed through the incorporation of new parent material from below, although the thickness of the soil remains constant. In case this normal erosion is reduced, as on flat relief, or increased, as in steep, hilly areas, soils varying from the normal are

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[6] Erosion is used here in the sense of a normal process occurring in all normal soils and is not to be confused with the removal of soil by destructive erosion which may occur locally as a result of using land for purposes to which it is naturally unfitted.

developed. It might be added that such soils are commonly less productive; in the first case because of more thorough leaching and in the second, because of the thinner solum. In the development of soils from unconsolidated rocks a certain amount of erosion is necessary for the genesis of the normal profile (and for a productive soil) ; whereas excessive erosion leads to the development of a thin, less productive soil. The thinner solum developed on hilly land is due in part to the increased removal of material by erosion and in part to the increased surface run-off of water, leaving less moisture for the growth of plants and consequently slowing down the soil-forming processes.

A series of profiles is sketched in figure 2 showing the general relationship between relief and soil morphology in an area where the normal soil belongs to the Gray-Brown Podzolic group. The Crosby soil shown in this figure, developed on flat relief where there is no
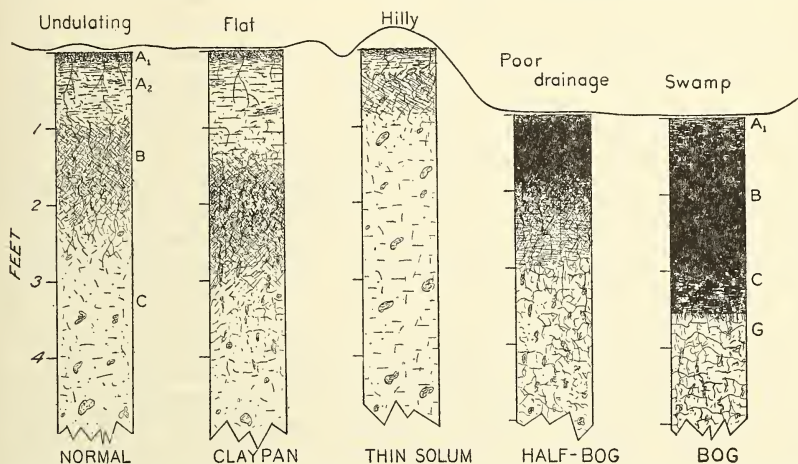
FIGURE 2.—Soil profiles developed from similar parent materials but varying in surface relief. Note that a thin solum is developed on hilly land because of excessive run-off and erosion ; whereas the flat upland has too little erosion and a highly leached upper part of the solum with a dense claypan in the lower part of the solum. Examples from the detailed soil classification include : Miami, Crosby, Rodman, Brookston, and Carlisle.

deposition, is more acid, has a deeper leached horizon, has a more dense, tenacious B horizon, and is less productive than the normal soil (Miami). Such soils are rather common in many parts of the United States and owe their infertility largely to a lack of normal erosion. Many soils in eastern United States, which have been commonly described as "worn-out", are of this type, but they never were productive. Some of General Washington's experiments with soil fertility came to little because of such soil. In lowland areas, subject to excessive moistening, dark-colored intrazonal soils are produced, because of the restricted decay of plant remains.

In the arid and semiarid regions analogous intrazonal soils are developed with differences in relief. In semiarid regions the sloping areas may have soils rather similar to those of a still drier region. Thus the hillsides within the belt of Chernozem may have soils somewhat similar to those normally found in the belt of Chestnut soils. In the lowland areas salty soils are found. The more de-

tailed development of the intrazonal soils produced under excessive moistening in the humid regions and under the influence of excess salts in the arid regions will be discussed under the appropriate soil processes.

AGE

The biological constructional forces in soil development naturally require considerable time before the soil comes into equilibrium with its environment. The examples shown in plate 10 are mature soils, in the sense that these soils have already developed their characteristic properties and are in equilibrium with their environment. Under certain conditions, soils may be found which because of their youth have not fully developed those characterstics which are normal for their environment. In some instances, such soils may be of great practical importance for the growth of plants. These "skeletal" soils include those developed from fresh deposits of sediments, such as stream alluvium, deltas, lake and ocean beaches, dunes, and freshly deposited lava flows. Fresh deposits of weathered rock are constantly being produced through the action of geological processes, and, as soil develops, in its initial stages the characteristics will be largely those inherited from the parent material; but slowly these are lost with the development of a mature soil.

A series of old stream terraces frequently affords an excellent opportunity for the study of these remarkable changes as one proceeds from the fresh alluvium of the immediate flood plain up to progressively higher and older terraces. Similarly, a striking series of changes may be observed with sand dunes of progressive ages since their fixation by plants.

In some instances these young soils are actually more productive of crop plants than adjoining mature soils. The flood plains of many rivers and small streams of humid United States offer examples. As these soils become altered by the dominant soil-building processes of the region they become less productive for those crop plants which are most unlike the native plants under which the mature soils of that region develop. In a strict sense, fresh deposits of sediments or exposures of rock are not soils but parent material. The term "alluvial soils", although in common use, is somewhat illogical, inasmuch as it is not the soil which has been moved or deposited but the parent material from which any one of a great many soils may be developed, depending on the other factors of the environment. If soils erode the material removed is no longer soil in a strict sense, but when redeposited may become parent material for a new soil.

THE PROCESSES OF SOIL DEVELOPMENT

Depending upon the nature of the environment, there are seven general processes of soil development: Calcification, (2) podzolization, (3) laterization,[7] (4) salinization, (5) solonization, (6) solodization, and (7) gleization.[8] The zonal groups of soils of the well-

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[7] Strictly speaking, laterization refers more particularly, in certain aspects, to weathering than to soil formation.
[8] Gleization (gleī + zātion) is a term used to include those processes under which soils having a glei horizon develop, such as Bog, Half-Bog, and Wiesenboden (swampy and poorly drained soils of the humid regions).

drained uplands are produced by modifications of the first 3 processes, and the last 4 are operative in the genesis of the intrazonal soils.

CALCIFICATION

The calcification process of soil development is most typically maintained under grasses or grasslike plants and conditions of restricted rainfall. There may be considerable leaching, but not enough to remove the carbonates of calcium (lime) and magnesium entirely, and these accumulate in the lower part of the soil, usually just under the solum, whereas the more soluble salts are removed with the drainage water.

Under such an environment the plants bring bases (and phosphorus) from the lower to the surface horizons in relatively large amounts. The soil does not become acid to an important degree, and the colloids, both organic and inorganic, remain saturated largely with calcium, and consequently relatively immobile.[9] As these conditions are favorable to a micropopulation predominately of bacteria, the products from the decomposition of organic matter are relatively insoluble and remain in the upper part of the soil.

Normal soils developed under this process have very little, if any, movement of clay or other colloidal material from the A to the B horizon. Those elements most commonly essential in plant growth are naturally conserved in the upper part of the soil. The depth of the color, content of organic matter, and thickness of the solum will depend largely on the vegetation—the type of grasses and their abundance.

This calcification process is dominant in the genesis of several of the important zonal groups of soils shown in plate 10. Others are influenced in varying degrees by this process, but in these cases its complete effects are opposed by other processes, especially podzolization which is, in a broad sense, the negation of calcification. Starting with the most humid upland grassland areas are found the Prairie soils.[10] With these soils podzolization has had some influence and the soils do not have the horizon of calcium carbonate accumulation. They are very dark brown in color, high in their content of organic matter in the upper part of the solum, and they are well supplied with the elements necessary for the growth of grasses and other herbaceous plants.[11] The high natural fertility of these soils, combined with their favorable climate, make them among the most productive in the world for grains and grasses. In passing from the Prairie soils to regions having a somewhat drier climate, one crosses the important boundary between those soils having a horizon of calcium carbonate accumulation (Pedocals) and those which do not (Pedalfers).

The Prairie soils are apparently not to be found, at least in any considerable area, except in the United States. They have some of the characteristics of the Chernozem group, but the main body of these dark-colored soils in central United States has developed un-

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[9] On flat relief the surface soil may become so wet under periods of extreme moistening as to favor downward washing of even calcium clay. Such movement is primarily mechanical and takes place largely in the structural openings or cracks. To the extent that this action influences the soil, a morphology varying from the normal may be expected.
[10] See the outline map shown in figure 4 for the general location of the various zonal soil types. For more exact cartographic expression of these general soil areas see reference cited in footnote 3.
[11] See table 1 for a summary description of each of the zonal groups of soils.

der a climate similar to that of the Gray-Brown Podzolic group. The grass vegetation has been able to return sufficient calcium to the surface soil to prevent any appreciable dispersion of colloids.

In the normal Prairie soils under discussion there has been but relatively little movement of colloidal material from the surface soil to the lower horizons. Within this region there are soils closely related to this group, however, which have a considerably higher content of clay in the B horizon than in the upper A horizon. To the extent that such soils have pronounced textural differences within the profile they are intrazonal. These soils are to be found on the areas of flat, or nearly flat, relief and may owe their morphology to the influence of ground water, to excess salts (solodization), or to the concentration of clay by simple downward washing, especially where the parent materials are heavy.

As the continual return of calcium is necessary to prevent the degradation of these soils through podzolization, this question naturally suggests itself: In time will not the bases leach to such an extent and to such a low level as to be out of reach of grass roots in sufficient quantities to prevent podzolization? This is, of course, possible, but probable only after a very long time under virgin conditions, owing in part to the slowness of the leaching and in part to gradual renewal of the soil profile from the bottom as the normal erosion, characteristic of the normal soil, removes the surface.

The next zonal group of soils after leaving the Prairie soils is the Chernozem, found in the most humid part of the drier region having soils with a calcium carbonate horizon. The grasses grow luxuriantly in this region and have produced black soils, very high in their content of organic matter, and very fertile for grasses and other herbaceous plants. The calcium and magnesium carbonates, produced through carbonation in the surface soil of the calcium and magnesium brought up by the grasses, are not leached beyond the reach of the grass roots. It will be noted that the presence of these carbonates, as such, in the parent material is in no sense necessary for the development of the characteristic lime zone. It is only necessary that calcium from some mineral be available to the plants. Chernozem and other Pedocals are frequently developed from weathered acidic rocks containing calcium in feldspars and other minerals. Such calcium is brought to the surface by plants and, after their decay, is united with carbonic acid to form calcium carbonate.

The group of Chernozem soils is one of the most important in the world. The black soils of the Russian steppes and of the plains of North America and South America belong with this group, as well as extensive areas in India and smaller areas elsewhere. Minor variations, especially in the intensity of the black color, obtain within the Chernozem group as influenced by differences in temperature. The southern Chernozem is not so dark as the northern Chernozem. These soils are well adapted to the small grains, especially wheat, and furnish the greater part of the world's breadstuffs (pl. 4). Although somewhat more fertile in the sense of their content of mineral plant nutrients than the Prairie soils, they are somewhat less productive, as the rainfall is lower and the climate more hazardous. As the tall-grass prairie, under which the Chernozem has developed, exerts the most powerful soil-building force, there is less variation within Chernozem than within the other soil groups.

In progressively drier climates the vegetation is more sparse, and consequently the soils become lighter in color and the solum thinner. First beyond the Chernozem group is the group of Chestnut soils, followed by the Brown soils, Sierozem (Gray) soils, and finally the Desert soils. Certain soils of the hot deserts have a reddish surface due to slight laterization. The Chestnut soils are fertile and extensively used for wheat, but the climate is hazardous. The Brown soils also are used for wheat, but the climate is so hazardous that the more rolling and otherwise less productive land is used for grazing, as the native short grasses provide excellent pasture for range animals. The Sierozem soils are low in organic matter, have relatively shallow solums over the lime zone, but are moderately fertile. The rainfall is too low and the climate too hazardous for much dry farming, but these soils are suitable for grazing and the most favorably situated areas can be irrigated successfully (pl. 5, A). These soils merge into the Desert soils (pl. 5, B).

In addition to these zonal soils, developed under the general influence of calcification, the soils of the Rendzina group must be mentioned. These soils are black and have developed under a grass vegetation. The black color and chernozemlike character of the surface soil is maintained, even under a humid climate, such as that of Alabama, because an abnormally high content and availability of calcium carbonate in the parent material favor the calcification process. Ordinarily these intrazonal soils are expected only in the humid region where they are found developed from soft parent materials, high in content of calcium carbonate, such as marl. Examples may be found, however, associated with Chernozem and Chestnut soils. Here the contrast is not so striking, but with careful examination the Rendzina can be distinguished by its shallower solum overlying extremely calcareous material. Some of the glacial deposits in the northern Great Plains of the United States are so rich in lime as to be responsible for a suggestion of rendzinalike soils in many places.

PODZOLIZATION

The podzolization process is dominant under humid climates and forest vegetation. The details of the process vary under different conditions and in the several groups influenced by it, but podzolization is typically active in the formation of the Podzol soils of the northern humid regions and especially under the coniferous forest (although they are often well developed under hardwood and mixed coniferous and hardwood forests). Under these conditions there is sufficient moisture to remove the soluble salts, including the less soluble carbonates of calcium and magnesium, completely from the soil. Trees feed more lightly on bases than do the grasses, and not sufficient bases are returned to the surface soil to prevent it from becoming acid.[12] Consequently the colloids become partly or almost wholly saturated with hydrogen.

Attention has already been drawn to the differences between coniferous and deciduous trees as regards their base cycle. To the extent that they have a lower content of bases in their leaves and

[12] A small group of soils, known as "Ramann's Braunerde" and Brown Forest soils, are developed under a forest growth which has been able to furnish sufficient bases to the surface soil for the prevention of podzolization. These soils are brown or dark brown and are somewhat similar to the Prairie soils. They are apparently not developed to an important extent in the United States.

twigs, the conifers favor podzolization. Especially in the drier parts of the region having soils developed through podzolization the relatively shallow rooted conifers may allow less percolation through the surface soil than more deeply rooted hardwoods, thus having, under these conditions, an influence to retard podzolization. For example, in the northern Lake States, better developed Podzol soils may be found under a hardwood forest than under the pine forest.

The toxic action on the bacteria, especially of tannins from the trees is, at least partly, responsible for the predominance of fungi in the surface soil. Decomposition of organic matter by these organisms leads to the production of organic acids favorable to the reduction and solubility of iron. Both the soluble organic matter and the hydrogen-saturated organic colloids favor the mobility of the inorganic materials, especially iron and inorganic colloids. In the normal soil, under conditions of good drainage, the soluble iron moves downward, becomes oxidized, and accumulates in the B horizon; and a large proportion of the colloids, both organic and inorganic, become precipitated in this horizon.

Several factors may be involved in this accumulation in the B horizon. Frequently the parent material contains sufficient bases, especially calcium carbonate, to cause flocculation in the lower part of the solum. In many places the moistening of the soil is extended downward only a short distance, and subsequently any materials which might have been in suspension are deposited. Occasionally, in certain parent materials, the lower strata, at a depth ranging from about 2 to 5 feet beneath the surface, are coarser in texture than the material above. In such a case the capillary tubes are broken above the coarse-textured stratum, and the downward-moving water accumulates in the bottom of the fine capillaries. During subsequent dry periods this water moves upward, leaving the finer material. As the materials pass from the surface downward the unstable organic anions produced by the fungi, and partly responsible for the reducing conditions, are themselves oxidized and their reducing influence is removed.

Whatever the exact cause or causes in this complex situation the fact remains that the surface soil becomes impoverished of fine colloids and organic matter and of those elements considered most necessary for the nutrition of crop plants, with a concentration of colloids and of iron (and frequently of alumina) taking place in the B horizon. A soil developed under this process is acid throughout the solum. Such a soil as the Podzol, formed under extreme podzolization, is a soil entity entirely different from the Chernozem (pl. 6). Whereas the latter has been developed under a vegetation similar to many crops and is considered a fertile soil for these plants, the Podzol is not considered fertile although it is well adapted (and in a sense fertile) for the trees under which it has developed.

South of the group of Podzol soils lie the Gray-Brown Podzolic soils on which are located the majority of the centers of Western Civilization. These soils have developed under a deciduous forest with a moist, temperate climate. Although varying in minor details these soils also are developed under a podzolization process similar to but not identical with that giving rise to the Podzol. The deciduous trees, however, return bases to the surface of the ground more rapidly than do the coniferous trees, although they are not so effec-
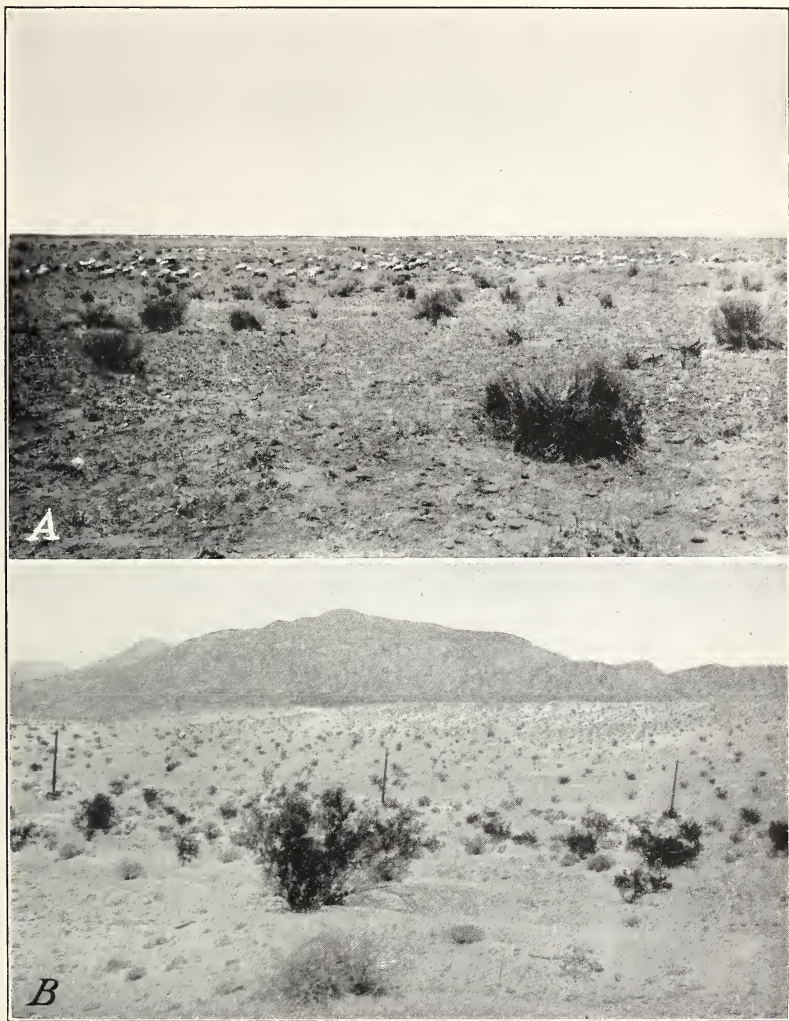
A, A view of the Sierozem (Gray soils). Grazing is the principal agricultural enterprise in this soil region, except where the land is irrigated. B, A Desert soil landscape which affords practically no vegetation for man or beast without irrigation. The hummocky surface attests to the frequent sand storms.

PLATE 6
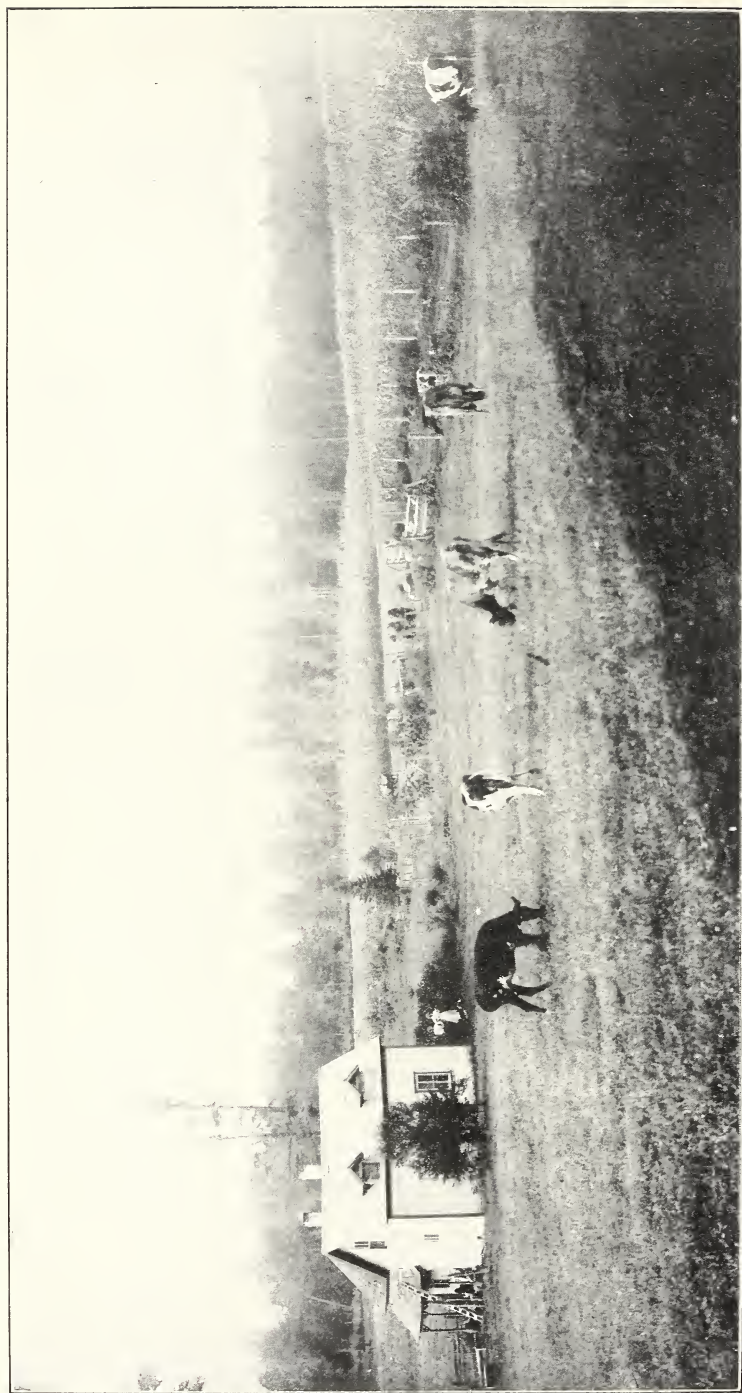
View of a small subsistence farm, typical of those adapted to the soils of the Podzol group. Small acreages of a rather wide variety of crops and pasture, especially for dairy cows, form the basis of the farm unit.

PLATE 7
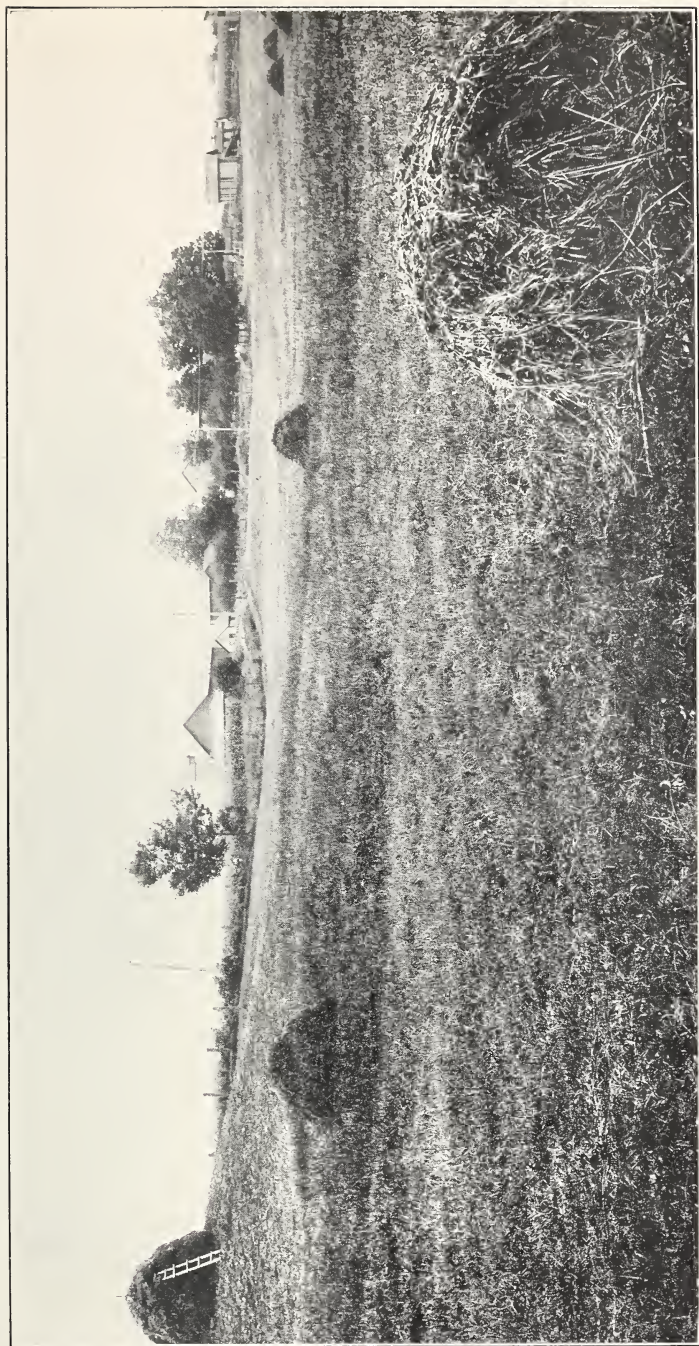
A typical rural scene in the region of the Gray-Brown Podzolic soils. A very wide variety of crops can be grown on these soils, and many kinds of livestock are raised

PLATE 8
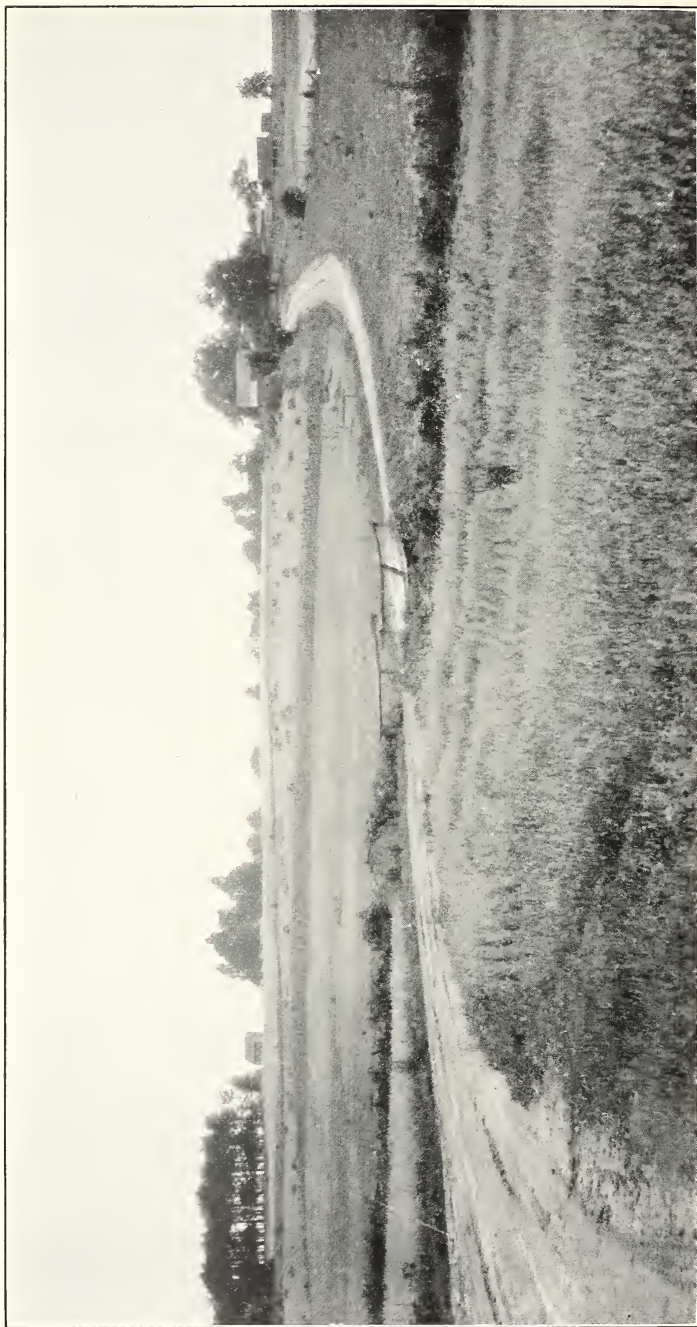
A typical rural scene in the Red soil region of southeastern United States. Such soils are especially used for subsistence crops with some tobacco, cotton, and peanuts.

tive in this respect as the grasses. The soils are naturally more fertile for crop plants than those of the Podzol group, but less so than the Chernozems. Considering their medium fertility, however, together with the desirable climate which allows the growth of a wide variety of plants, these soils are admirably adapted to the development of stable agricultural communities of the general farming type, such as those on these soils in the United States (pl. 7). It might be added that, although these soils are only medium in natural fertility, they are " responsive " and under good farming practices, including some fertilization and liming, produce as well or better than Chernozem.

Farther south and into the Tropics the podzolization processes are dominant in the development of the normal soils. In the warmer humid countries laterization and podzolization both play an important part, but the former process, to be discussed in more detail, is, perhaps, more directly concerned with weathering, or the accumulation of parent material. In many cases of actual soils there are found Laterite soils where podzolization has been absent or only feebly effective. The Red soils of southern United States have formed under the influence of both processes, as have their associates, the Yellow soils. In the latter group a previous condition of imperfect drainage may be responsible for a greater hydration of the iron compounds with the resultant yellow color rather than the red color.

At the general boundary region of the Pedocals (soils with a layer of accumulated calcium carbonate) with the Pedalfers (soils wherein iron and/or alumina accumulate) there is competition between podzolization and calcification as the dominant soil-building process, just as there is competition between the grasses and the trees for domination. The Prairie soils are developed under grasses, but in the more humid part of this boundary region. Although the calcification process has been dominant, there is no layer of accumulated carbonate as in the Chernozem; and the soils usually exhibit some evidence of podzolization, especially in the B horizon. There is some reason to believe that these soils are slowly becoming acid and more podzolized. As the upland normal Prairie soils under observation in the United States are essentially all cultivated now, any natural changes in vegetation are obscured. Of course, any management of these soils which returns less organic matter and bases to the surface than the native plants hastens their degradation. There are a great many evidences, gained from a study of the morphology of the Prairie soils and the adjacent Gray-Brown Podzolic soils, which point to the probability that if left in a natural state forest vegetation would gradually cover these soils, thus greatly stimulating podzolization and changing them to Gray-Brown Podzolic soils.

In that part of the general boundary region lying between the Chernozem and the Podzol, many examples of transitional soils may be found having characteristics of both soil groups. Such soils are usually referred to as degraded Chernozem. Their total area is small as conditions bringing about an almost equal balance between the two soil processes are not easily maintained, and apparently only a comparatively short time in the dominant role is required by either, to obliterate the dominant soil characteristics associated with the other.

LATERIZATION

The laterization process is, perhaps, more strictly a geological process than one of soil building. The group of Laterite soils has not been so extensively studied as the Podzol and Chernozem, and their morphology and genesis are less well understood.

This process is typically operative under the extreme moistening and high temperature of tropical climates. The northern limit of the region is not sharp, and there is a wide transitional area between the Laterite of the equatorial regions and the Gray-Brown Podzolic soils of temperate regions. These transitional groups of soils are represented in plate 10 by the Red (and Terra Rossa) soils and the associated Yellow soils. Under the humid tropical climate the weathering process is intense. As hydrolysis of the minerals proceeds rapidly, the bases are released to the immediate solution around the individual grains very rapidly. A luxuriant vegetation grows and decomposes rapidly, thereby bringing bases to the surface and releasing them in large amounts. Under these conditions the solution around many of the individual particles is neutral or alkaline, thus favoring the solution of silica, especially that of the alumino-silica complexes, whereas the iron and alumina remain largely insoluble.

Where such conditions obtain the resultant material would consist largely of iron oxides and alumina with quartz-silica, manganese, and other resistant compounds of less importance. As hydrolysis nears completion, the supply of bases becomes depleted, the base-exchange capacity is lowered, an acid reaction may develop in the soil, and podzolization begin. Thus normally a podzolized profile developed from the material produced through laterization may be expected.

The material produced by laterization has a relatively high content of iron and alumina with a corresponding low content of silica. Lateritic clays are less sticky and have a lower capacity for the adsorption of bases than other clays. As pointed out before there is a wide transitional region between the Gray-Brown Podzolic soils and the true Laterites. Although there are no true Laterites in the United States, the Red and Yellow groups of soils are lateritic, and to the extent that this process has influenced them the soils exhibit the characteristics of the Laterite (pls. 8 and 9).

Associated with the normal Laterite are many youthful soils, developed from volcanic deposits, alluvial deposits, and similar materials in all stages of development. The older soils frequently have been defaced, in part, by erosion, coincident with the natural development of drainage. Many times there has been sufficient erosion for the removal of the podzolized upper portion of the soil profile. Although the term Laterite is used and applied to the soils of the Tropics probably a somewhat greater degree of nonconformity is to be found than within the other zonal groups. Further research is needed in order to understand the morphology and genesis of this group of soils. Although considerable work has been done with soils in tropical countries, not many morphological studies have been made; and the most of the chemical and morphological data available are obtained either from young soils or from those developed from stratified parent rock, thus making it difficult to be

certain as to which characteristics are truly pedological and which are inherited from the parent rock.

SALINIZATION, SOLONIZATION, AND SOLODIZATION

These three soil processes can be discussed together most conveniently, as they operate in the genesis of the intrazonal soils associated, in general, with the zonal soils of the subhumid to arid regions wherein bases accumulate in all or part of the soil profile. These intrazonal groups include Solonchak, Solonetz, and Soloth, in the usual order of their genesis, one after the other. In general, these soils are referred to as "alkali" soils, especially in North America. This is an unfortunate name and its continued use should be discouraged. It is altogether too broad and, as generally used in the United States, includes soils quite unlike as to their morphology, genesis, and ecological relationships. The Solonchak soils sometimes are called more aptly, "salty" or "saline" soils; and less accurately, because they are not commonly highly alkaline, they are referred to as "white alkali" soils. The Solonetz soils are commonly known as "black alkali" soils. As these soils are usually dark in color and highly alkaline such a name is not so undesirable, at least from a practical point of view. There has been no common name given to the Soloth soils, and they should scarcely be included under "alkali" soils, since they are neither salty nor alkaline in the solum.

All these soils are found in places that are receiving, or have received at some previous time, excess salts. The salts may have been present originally in the parent material, as in the case of certain marine deposits, and not leached out as would be the case under a heavy rainfall. More commonly, however, the conditions necessary for their development are found in low, poorly drained places, or seepage areas, where salts may accumulate on evaporation of the water that leached them from adjoining land. These are areas of periodic excessive moistening and drying.

SOLONCHAK

The Solonchak represents the first stage in the development of this group of soils. The process under which they develop is salinization. In the Solonchak there is an excess of the soluble salts, and usually at least some of the salts are monovalent (like sodium), although not necessarily so. In case the salts are all divalent (like calcium), the properties of the soil in this stage are not greatly different, but as drainage develops the soil changes into one belonging with the zonal group for the region, such as a Chernozem or Sierozem, rather than into Solonetz, as is usually the case.[13]

If sodium is present as the chloride or sulphate, some of the base-exchange colloids become saturated with sodium. When in contact with water such colloids are highly alkaline and easily go into colloidal suspension; but while excess sodium salts are present both of

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[13] It is commonly considered that magnesium acts similarly to calcium in the genesis of these soils, but recent laboratory investigations have shown differences between the calcium colloid and the magnesium colloid, which make this assumption questionable. Further research on the magnesium Solonchak and its derivatives is needed.

these actions are prevented, as the electrolytes prevent deflocculation of the colloids and the excess sodium ions in the solution prevent hydrolysis of the sodium from the exchange complex. Therefore, while in the Solonchak stage of development the soils are not highly alkaline.[14] But as solonization, to be discussed subsequently, begins the soil may become highly alkaline, even though morphologically such transitional soils are more nearly Solonchak than Solonetz.

Because of the excess salts the Solonchak is structureless; the colloids are highly flocculated. Streaks and spots of salt are to be seen throughout the soil, but there is no striking profile character as in the other groups of soils. A great many forms, however, may be observed, depending on how the salts are accumulated. Two general subtypes may be recognized on this basis: (1) The less common " flooded " type, wherein the salts were introduced by a more or less uniform flooding from above, as in an old lake basin, and (2) the more common " capillary " type wherein the salts came upward with the rise of capillary water from some comparatively shallow ground-water table. This latter type may again be further divided into two groups: (1) The " exterior " or " puff " Solonchak, in which the salts have come to the very surface, producing a thin hard crust, usually puffed, and immediately underlain by a soft, mealy layer some few inches in thickness; and (2) the " interior " Solonchak, wherein the ground water came up only part way by capillary action. In this latter case the water moves up the remainder of the way as vapor, leaving the salts concentrated in a horizon at some few inches (or even feet) beneath the surface. When to these complexities are added the great possible range in the total amount of salt and proportionate amounts of the various kinds of salt, it is clear that a great many varieties of Solonchak are possible.

Such soils may form directly from almost any unconsolidated parent material provided the environment is favorable to their formation, or they may develop from some normal soil, thereby destroying that soil and creating its own morphology. Many failures experienced in ill-conceived or ill-managed irrigation projects testify to the speed and effectiveness with which Solonchak soils may develop.

SOLONETZ

The Solonetz soils are characterized by a hard prismatic or columnar structure with hard aggregates. Frequently they are described as " pillared alkali." Typically these soils have a relatively low content of soluble salts, and a relatively high alkaline reaction as compared to the typical Solonchak.

As drainage of the Solonchak improves, the excess soluble salts are removed. In most instances the Solonchak contain a considerable amount of exchangeable sodium, and when the excess salts are leached out the colloids are dispersed and the soil becomes highly alkaline, owing to the hydrolysis of the sodium to form sodium hydroxide. (This, of course, passes to sodium carbonate as the sodium hydroxide reacts with carbon dioxide.) In the presence of this highly alkaline material the organic matter is highly dispersed and distributed over

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[14] Except in the unusual case of flooding with sodium carbonate which has been introduced through the leaching of a Solonetz at a higher level. This condition is by no means unknown in certain irrigated lands.

PLATE 9
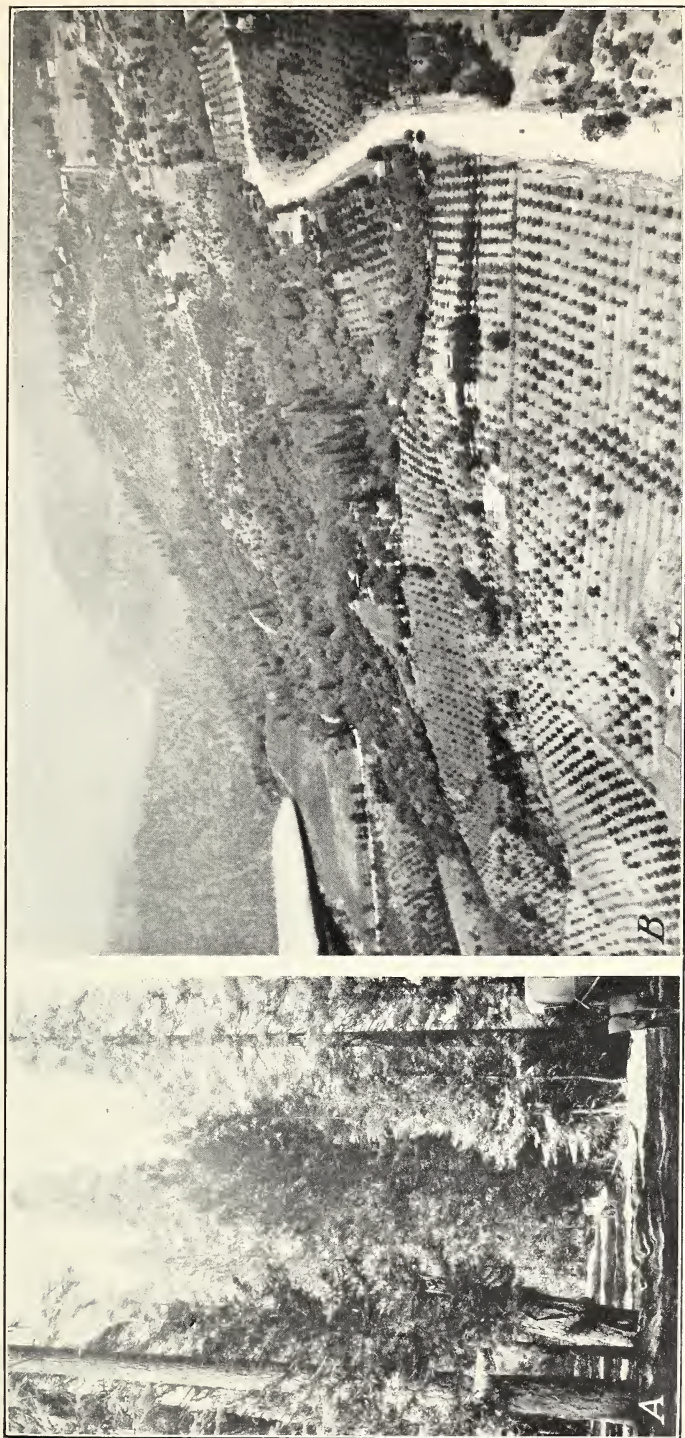
A, Typical forest on a Red soil of the Pacific coast; *B*, aerial view of orchards on a Red soil of the Pacific coast.

the other soil particles, thereby deepening the color. Thus Solonetz soils are frequently known as " black alkali ", although in many places the color is brown or dark brown where the vegetation is sparse. This process of solonization, by which a Solonetz is produced, thus involves desalinization and alkalinization of the Solonchak.

Although the Solonetz possesses characteristics unfavorable to the growth of plants, vegetation is, in general, more luxurious on these soils than on Solonchak. By the use of gypsum or sulphur and the improvement of drainage, the Solonetz soils are frequently made productive for crops. The development of these soils can be and frequently is induced through irrigation. The simple drainage and irrigation of a Solonchak containing sodium salts, of course, leads directly to the solonization process.

SOLOTH

As soon as Solonetz has formed, the highly dispersed colloids tend to move downward, thus producing surface horizons lighter in color and lower in clay content. At first there is a platy, friable, whitish A_2 horizon developed near the surface and this is underlain abruptly by a dark, columnar B horizon with well-rounded caps on the vertical prisms. This process of removal by leaching is solodization and resembles the podzolization process, except that the original mobility of the colloids is due to the presence of exchangeable sodium rather than hydrogen. As solodization continues, the surface horizons deepen at the expense of the lower horizons and the soil becomes acid.

As the Solonetz becomes solodized, conditions are improved for the growth of those plants native to the adjacent normal soils and for crop plants. The completely developed Soloth is rather uncommon and would be expected in association with the Chernozem, in the most humid part of its region. As the normal vegetation returns, the calcification process becomes active and tends to change the soil to that normal for the region. In drier climates than that of the region of Chernozem, the completely developed Soloth, which is acid throughout the solum, is almost unknown.   .

TRANSITIONAL STAGES

Many transitional stages may be found between Solonchak and Solonetz, Solonetz and Soloth, and Soloth and the normal soil. Nearly every Solonetz shows at least some of the characteristics of either Solonchak or Soloth. In a great many cases, especially where the salts have been introduced into the soil mass through capillary movement from below, these intrazonal soils occur in roughly elliptical spots, ranging from about 10 to 20 feet in diameter. After the soil in the spot has developed the profile of the solodized-Solonetz, having a friable, loose surface soil underlain by a heavy, columnar horizon, a break in the surface sod may allow erosion by wind and water, leaving the hard, dark clay exposed. Millions of acres of land in the western plains of the United States and elsewhere in the world are covered by these shallow, usually barren, basins. These are locally known as " scabby spots ", " burn-outs ", " buffalo wallows ", " slick spots ", and similar appelatives; and have been most aptly called " smallpox on the face of the steppe." Such land is

greatly reduced in its usefulness for grazing, as these spots support but little grass. When plowed the soil in the spots is very hard when dry and sticky when wet, so as to be unproductive for crops. By careful management, however, such conditions can be ameliorated and the lands made more productive within a few years through the addition of organic matter and careful tillage.

Under natural conditions the soil of these bare spots becomes slowly covered with grasses, and a new soil profile is formed. In time the plants slowly develop a soil intermediate between the Solonetz and the normal soil. The general evolution of this group of soils is shown in outline form in figure 3.

Frequently sufficient sodium was contained in the parent material or added to it by seepage water to encourage some solonization and solodization in soils, but not enough to produce the complete morphology of the Solonetz or Soloth. Many such transitional soils having some of the morphological characteristics of the Soloth, especially the concentration of colloids in the B horizon, are found associated with the normal soils of the Prairie group and the groups of Pedocals. To the extent that sharply defined textural differences obtained in soils of these groups, they are intrazonal. It has already been pointed out that other processes may also bring about such concentrations of clay on flat relief.

GLEIZATION

Gleization connotes the general process by which those soils having a glei horizon are formed. This light-colored glei horizon is formed, due to lack of oxygen, under conditions of excessive moistening in the mineral portion of the soil. The material in the glei horizon is ordinarily more or less sticky, compact, and structureless. The reduced or deoxidized compounds of iron impart a grayish or bluish cast to the soil. Where the water table fluctuates, giving rise to the alternation of oxidizing and reducing conditions, the glei horizon is characterized by mottlings of yellow and rusty brown, especially along structural cracks and root channels. Under poorly drained conditions and in the presence of organic matter the solubility of iron, manganese, calcium, and magnesium is increased. Because of a lack of leaching these compounds remain and the silica also is not lost. In many places the iron may seep out at some exposure, such as a stream bank, and, on contact with the air, be oxidized and precipitated to form bog iron.

Under conditions of excessive moistening of the soil in those regions having a relatively low evaporation, and especially where the rainfall is abundant, the organic material accumulated through the growth of plants is not completely decomposed to humus as in such a soil as the Chernozem. Under such conditions peat is formed and Bog soils developed. The peat material may be accumulated from the remains of a great variety of plants including swamp forests, both conifers and hardwoods, sedges, shrubs, and mosses.

The ground water may have the influence of producing crusts or concentrations at its surface within the soil. For example, if the ground water contains reduced iron this may be oxidized and deposited in the soil near the level of the ground-water table, producing an iron crust, as in some lateritic soils, or a marked ortstein, as in
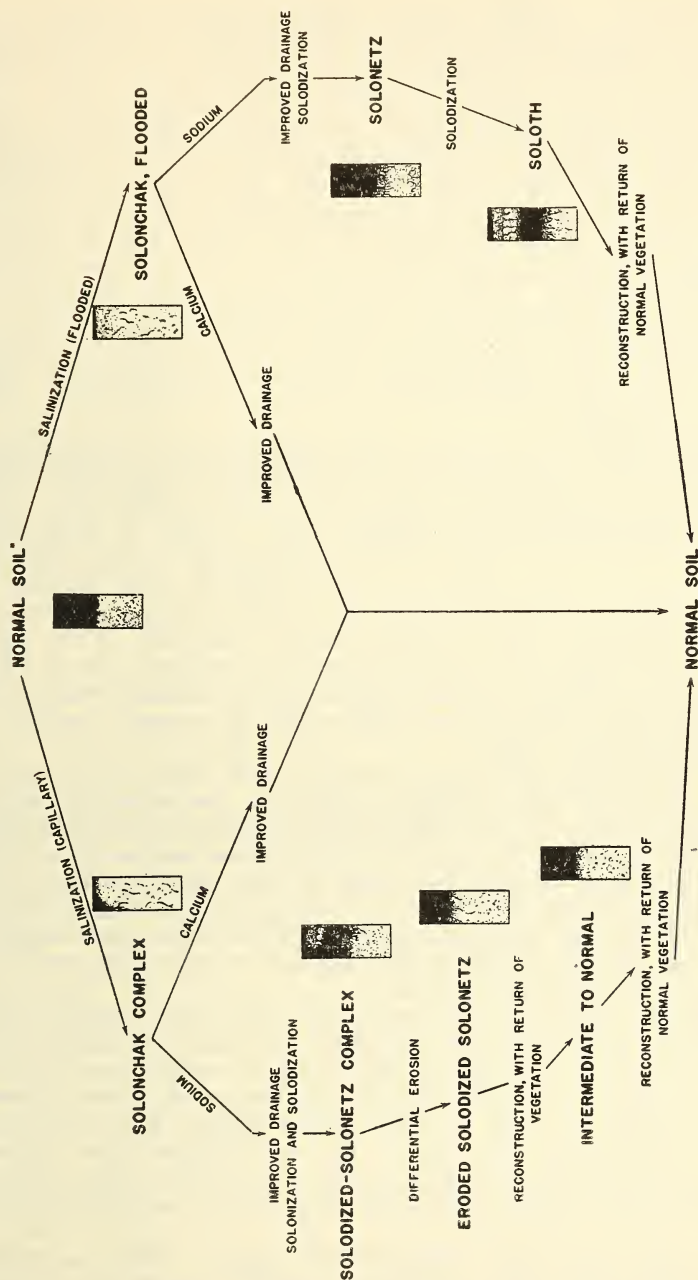
FIGURE 3.—An outline of the cycle of evolution of the intrazonal soils, Solonchak, Solonetz, and Soloth. It may be noted that these are not mutually exclusive categories but that many transitional soils are found, especially in those cases where the intrazonal soils occur with the normal soils as a complex.

the ground-water Podzol, provided there is sufficient oxygen in the soil above.

These elementary processes, the formation of glei, and the formation of peat, are combined under a wide variety of conditions to produce the intrazonal soils of this group. Closest to the Chernozem and Prairie soils is the Wiesenboden (Meadow soil). These soils are developed with a vegetation of grasses or grasslike plants, and under poor drainage glei is formed. Although considerable organic matter is accumulated in the surface layers, it is rather well decomposed and is incorporated with the mineral soil rather than resting upon the mineral material in the form of a peaty layer, as is the case with the true Bog soils. The Wiesenboden is rarely acid, and where drained by artificial means provides some of the most fertile land in the world for crops. It is a not a zonal soil, but is to be found in small, naturally poorly drained areas within the other soil regions, especially in association with the Prairie and Gray-Brown Podzolic soils. The Wiesenboden is not to be confused with the Rendzina, although superficially the soils of the two groups may resemble one another.

The Bog soils are those of the true swamp, where peaty materials have accumulated under the influence of excessive moistening. The true parent material for these soils is the organic matter itself, and they are frequently termed " organic soils." Owing to differences in the character of the original organic matter, in the position and stability of the water tables, and in the reaction and content of soluble materials in the water, great variations may be expected, ranging all the way from the raw, coarse, acid soils of the high moors to the black, friable, alkaline soils of the low moors. The former are essentially useless for agriculture, but the latter are often highly developed and produce large yields of a great variety of vegetables and other crops.

As the Half-Bog soils occupy positions transitional between the Bog soils and the associated upland soils, they are frequently spoken of as " marsh border " soils. Essentially these soils are shallow Bog soils. When cultivated the surface organic layers become mixed with the mineral matter beneath, and many of them make excellent crop land where artificially drained. If the surface layers consist of raw, acid organic matter, and especially in places where such organic material is underlain by sand, the soils are naturally unproductive for crop plants, even when drained.

The Tundra soils are, in a sense, associated with the Bog soils because of their poor drainage caused by the ever-frozen substratum. They comprise the zonal group occurring in regions north of the Podzol. A glei is developed, and the vegetation of mosses, lichens, and shrubs tend to form a peaty surface layer. The severe and repeated freezing and thawing of these soils brings about a great deal of mechanical mixing. As the surface material freezes, pressure is exerted on the viscous mass beneath forcing it upward through cracks.

Various types of Alpine Meadow soils may be found in mountainous regions above the timber line, bearing resemblance to Tundra, to Bog, and to Wiesenboden.

OTHER INTRAZONAL SOILS

Although the main purpose of this discussion concerns the zonal and most important intrazonal groups of soils, it must not be overlooked that a few soils are found which are not members of any of these important morphological groups. Certain soils developed from recently deposited stream alluvium ("alluvial soils"), some of which are of great agricultural value, may be mentioned. Although such soils are of significance in agriculture and are of interest to the pedologist, they are immature and only in process of formation, as the accumulation of mineral and organic matter from outside sources is continually proceeding. After that process has ceased the normal profile develops, but in the meantime the characteristics of these soils are the result of local forces rather than broad pedological ones.

Another important group might be called, for want of a better name, "the sandy soils." In many places such formations as sand dunes and sandy outwash deposits furnish a parent material for soil consisting almost wholly of quartz. Normal soils cannot develop from such parent materials. The low content of clay and nutrient elements and the low water-holding capacity of the material inhibit the growth of the vegetation characteristic of the associated normal soils. Although from an areal point of view these soils are important, they are not of great importance in crop production except locally where economic and climatic factors are so favorable as to justify intensive fertilization.

SIGNIFICANCE OF THE ZONAL GROUPS OF SOILS

The previous discussion has dealt almost wholly with the genesis of the great groups of soils. It has been emphasized throughout that variations of great importance exist within these more general zonal and intrazonal groups, owing to the influence of local conditions of parent material, relief, and age. The examples of soil profiles shown in plate 10 represent, however, the normal conditions toward which all the soils are progressing. Particularly in a hill-valley region, such as many sections of eastern and far-western United States, enormous local differences in soils, especially from the point of view of their agricultural use, exist. One needs only to travel through such a State as Tennessee or West Virginia to observe the great influence of relief and parent rock on the formation and ultimate use of soil. In such areas, differences in native vegetation and climate are not great, especially from the point of view of soil formation. Even though the general character of the soils and their use is determined by these factors, those important differences within the group, so apparent to the local observer and so vital to the local resident, are largely brought about by local conditions of relief, parent material, and age.

When, however, the observer broadens his outlook and compares the soils of South Dakota or New Mexico with those of Tennessee or West Virginia, he realizes at once that those differences in soil of first importance are due to characteristics brought about by differences in native vegetation and climate. Although the glacial till covering much of North Dakota is not greatly unlike that of Michigan, the soils developed from this material in the two regions

have scarcely a characteristic in common, and their uses are as widely different. To illustrate in another way: Soils developed from granite are different from those developed from limestone in either Tennessee or South Dakota, but the soils developed from the one parent material in the two regions have differences of much greater significance than those between either pair of soils within one region.

The actual field investigation of soils gives detailed data. The soils examined exhibit, of course, those characteristics due to local factors as well as those due to the more general factors of vegetation and climate. In soil classification, as developed in the United States, the soil series is the fundamental unit. The series are divided into types on the basis of the texture of the surface soil, and these again into phases, according to minor variations, such as differences in stoniness and relief that are of importance in land use but not expressed by actual soil differences. The grouping of the soil series into higher categories is accomplished by bringing together those having certain fundamental characteristics in common. Thus, each of the zonal and intrazonal groups which have formed the basis of the present discussion include a great many soil series having the same general characteristics.

Although these great groups are not exactly confined to " zones " in a strict sense, they are approximately so because the fundamental characteristics which differentiate them, one from another, are directly or indirectly the result of climate and biological forces. The irregular pattern of land masses in respect to the ocean and the great variations in altitude introduce irregularities in the position of climatic, biological, and soil zones. In Asia, for example, the soil zones have a very general east-west trend. This is true also in eastern United States, whereas in the western and middle-western parts of the country the soil zones run roughly north and south. In figure 4 is shown the general distribution of the zonal groups in the United States. In order to bring out the relationships between these zonal groups more clearly an idealized distribution is shown in Figure 5. Of course, nowhere in the world will such an ideal distribution be found, because of irregularities in relief and climatic conditions. In mountainous regions the groups of soils have a vertical distribution. Mountains rising out of the Desert soil region may have Podzol soils near the timber line with several groups represented between them and the Desert. The differences between these great groups are those brought about largely by variations in climate and native vegetation.

In the development of pedology in Russia, scientists were more impressed by, and interested in, the distribution and character of these great zonal groups; whereas in North America the interest has been more especially concerned with the local investigations. Each type of study is important, and each yields data of great scientific interest and practical importance to land use. The more general relationships must be known for any comparison of regions or for any useful study of regional differences in agriculture and rural economy; and the detailed analysis and expression of local variations within the region must precede an understanding of differences among actual farms or other units of operation. Although

the study of the zonal groups has been undertaken only recently in the United States, a considerable advancement has been made because of the large amount of the detailed data available, which
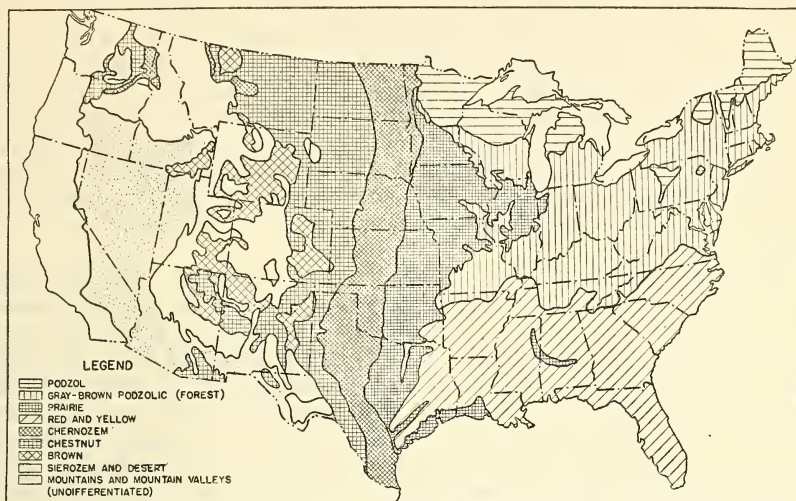

FIGURE 4.—General distribution of the important zonal groups of soils in the United States.

only need interpretation and generalization for application to the more comprehensive study.

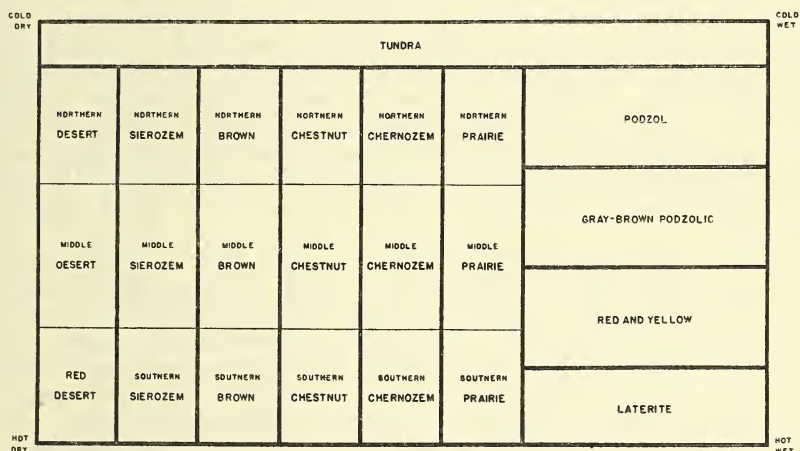In the study of land use, or for its considered adjustment, both types of information regarding the soil are of the utmost importance

FIGURE 5.—Relative positions of the important zonal groups of soils. Of these, Tundra and Laterite are not found in the United States. By comparing this sketch with figure 4 showing the distribution of the zonal groups in the United States it will be noted that the progression from right to left is interrupted by the mountains.

and necessity. In considering the broad aspects of land, the zonal groups of soils can be conveniently considered as great "natural land types", each with its own soil, climate, and vegetation, and

each having its own biological dynamic. Man is a part of these great landscapes and he is strongly influenced by them in many ways. Each group has certain aesthetic influences, reflected, for example, in folk songs which resemble more the landscapes from whence they originated than the races. Of more importance are the vastly different social and economic arrangements which man necessarily makes in these different zonal groups of soils, in an attempt to adjust himself to their potentialities for his use. For example, the Gray-Brown Podzolic soils allow the production of a wide range of crops, including the subsistence crops and fruits, and many kinds of animals. Although the native forest must be cleared away for crops, fuel and water are plentiful. Climatic conditions are favorable to crop production and are not so hazardous as in many other zones.

Although these soils have only medium fertility, the favorable and dependable climate combine to favor agriculture of the general farming type with small units, operated largely by the family and with a large percentage of the family living obtained from the farm (pl. 7). As the farms are small and close together opportunities for social organization are excellent. But because of the great freedom of enterprise and many opportunities in such a landscape, the people are not so driven to fundamental cooperation as are people in a region having limited possibilities. In the Gray-Brown Podzolic zone of soils, there are a dozen opportunities for a livelihood where the Chernozem or Brown soil zones offer one.

Turning now to the Chestnut group, one finds a different situation. Here the treeless landscape has a fertile soil, but there is little fuel and water is frequently scarce. The climate is not favorable to a wide range of crops, and it is undependable. Droughts may come and almost nothing grow whereas moist periods bring bountiful crops. Farms are large and extensively used for a few adapted crops, especially the cereals (pl. 4). Although these soils and the Chernozem were largely undeveloped agriculturally prior to the Thirty Years' War they now produce the bulk of the world's breadstuffs. Neighbors are far apart and opportunities for social contacts are less favorable than in the region of the Gray-Brown Podzolic forest soils. Nevertheless, as people have sharply limited opportunities they are impelled toward cooperation for the protection of their economic interests.

Similar relationships between the soils and their use exist within the other zonal groups. Each of these great zonal groups of soils is most productive for certain plants and animals and is adapted to certain types of enterprise. As a result, different arrangements must be made on each. These relationships have been summarized briefly in tables 1 and 2. Any plans or studies of agriculture and agricultural affairs must take full cognizance of these relationships. For example, the validity of comparisons of farm income depends, in part, on the type of farming possible. A relatively low cash income in the Podzol region may be reported from a farm family in better circumstances than one reporting a higher cash income from a farm in the Brown soil region where only a little of the family living may be obtained from the farm.

TABLE 1.—*General character and relationships of the zonal groups of soils* [1]

Zonal group of soils	Profile	Native vegetation	Climate	Soil-development processes	Natural fertility (crop plants)	Dominant agriculture
Chernozem	Black soil grading, at a depth ranging from 2 to 4 feet, into a whitish, calcareous horizon.	Tall-grass prairie	Temperate to cool, subhumid.	Calcification	Very high	Rather large farms with a comparatively low percentage of subsistence crops. Wheat is the dominant crop, with some other cereals, including corn. Social cooperation usually well developed.
Chestnut	Dark-brown soil, grading, at a depth ranging from 1½ to 3 feet, into a whitish calcareous horizon.	Mixed tall- and short-grass prairie.	Temperate to cool, arid.	do	do	Large farms with a limited choice of crops. Wheat is the dominant crop, with some other cereals. Social cooperation usually well developed.
Brown	Brown soil grading, at a depth ranging from 1 to 2 feet, into a whitish calcareous horizon.	Short-grass prairie	do	do	do	Very large farms with a sharply limited choice of crops unless irrigated. Wheat is the dominant crop under extensive dry farming. Considerable ranching in large units. Social cooperation usually developed.
Sierozem	Grayish soil grading into lighter colored calcareous material at a depth of about 1 foot or less.	Short grass and desert plants.	do	do	Medium to high (if irrigated).	Devoted to ranching in large units or irrigated, with intensive small farms closely dependent on community cooperation. Although a rather wide choice of crops may be possible under irrigation, the community frequently specializes.
Desert	Grayish soil, low in organic matter, closely underlain by calcareous material.	Desert plants	do	do	do	Mostly devoted to ranching in very large units or by nomads. Some is irrigated, with intensive small farms closely dependent on community cooperation. Although a rather wide choice of crops may be possible, the community usually specializes.
Red Desert.	Reddish soil, low in organic matter, closely underlain by calcareous material.	do	do	Calcification (with weak laterization).	do	Do.
Tundra	Dark-brown peaty layers over grayish horizons; substratum of ever-frozen material.	Mosses, lichens, and shrubs.	Cold, humid	Gleization (much mechanical mixing).	Medium	Mostly used for pasture and some for very short season crops. Hunting and trapping are associated enterprises.

[1] These statements are necessarily general and apply to the normal soils as illustrated in plate 10.

TABLE 1.—*General character and relationships of the zonal groups of soils*—Continued

Zonal group of soils	Profile	Native vegetation	Climate	Soil development processes	Natural fertility (crop plants)	Dominant agriculture
Podzol	A very thin organic layer on top of gray leached soil which is over a dark-brown horizon.	Coniferous forest (usually).	Cool, moist	Podzolization	Low	Small subsistence farms, with a rather wide variety of crops and with livestock, especially dairy cows. Very little wheat or corn. Alternate or associated enterprises include recreational institutions, lumbering, and hunting. There is a well-developed rural community life.
Gray-Brown Podzolic (Forest).	A rather thin organic layer over grayish-brown leached soil which is over a brown horizon.	Deciduous forest	Cool-temperate, moist.	do	Medium	Small farm units, with general farming, including livestock. A very wide variety of crops and animals can be produced. Both corn and wheat can be grown successfully. There is some tendency toward community specialization. Rural community life is well developed. There is much industrial development on these soils.
Prairie	Very dark brown soil grading through brown to a lighter colored parent material at a depth ranging from 3 to 5 feet.	Tall-grass prairie	Temperate, moist	Calcification (with some podzolization).	High	Medium-sized or small farm units, with general farming including considerable livestock. Well-developed community life with some tendency toward community specialization.
Yellow [2]	Thin organic layer over grayish-yellow leached soil which is over a yellow horizon.	Forest, largely coniferous.	Warm-temperate, moist.	Podzolization (with some lateralization).	Low	Small or medium-sized farms, with tobacco, cotton, and peanuts, and a rather wide variety of subsistence crops, but without much livestock. Local specialization with truck and fruit crops. Fair development of community life.
Red	Thin organic layer over yellowish-brown leached soil which is over a deep-red horizon.	Forest, largely deciduous.	do	Podzolization and laterization.	Medium	Small farms, with a rather wide choice of subsistence crops and some livestock. Considerable cotton and tobacco. Fairly well developed community life, with some local specialization.
Laterite	Thin organic layer over reddish leached soil over deep-red lateritic material.	Tropical forest	Hot, moist	Laterization and podzolization.	do	Local small tracts used by natives, with a wide choice of plants. Some large plantations developed for special crops under foreign management.

[2] These soils are, in a sense, intrazonal; in the United States they are too intimately mixed with areas of the Red soils to be indicated separately on a general map.

TABLE 2.—*General character and relationships of the intrazonal groups of soils*

Intrazonal group of soils	Profile	Native vegetation	Climate	Factors responsible for development of intrazonal soil	Soil-development processes	Natural fertility (crop plants)	Agricultural use
Solonchak	Gray thin crust on the surface (or salty layer beneath the surface). Grayish friable soil with streaks and spots of salt.	Sparse growth of halophytic grasses and other plants.	Cool to hot, sub-humid to arid.	Poor drainage (with salty accumulations).	Salinization	Very low	Some grazing or left as waste land.
Solonetz	Very thin to a few inches of friable surface soil underlain by dark, hard, columnar layer, usually highly alkaline.	Halophytic plants, with a thin stand of other grasses.	do	Improved drainage of a sodium Solonchak.	Solonization	Low (medium when reclaimed).	Some grazing, small areas reclaimed for use with associated normal soils.
Soloth	Thin brown horizon of friable soil over whitish leached horizon which is underlain by brown or dark-brown horizon.	Mixed prairie (usually).	Cool to hot, sub-humid to semi-arid.	Improved drainage and leaching of Solonetz.	Solodization	Medium	Used in connection with associated normal soils for crops or grazing.
Rendzina	Black (or brown) friable soil underlain by whitish, calcareous material.	Prairie	Cool to hot (usually temperate), humid to arid (usually humid mid).	Excess calcium carbonate in the parent material.	Calcification	Very high (usually).	Used in connection with normal soils (in humid regions similar to Prairie soils).
Bog	Brown peaty material, quite variable as to color and consistence. (May or may not have developed true soil profile.)	Swamp forest (or other plants, especially sedges).	Cool to warm, humid.	Extremely poor drainage, with abundant rainfall.	Gleization	Low to medium, with some few high (when drained).	Some drained areas used for special crops. A considerable part devoted to forest.
Half-Bog	Dark-brown or black peaty material over grayish mineral soil.	Swamp forest	do	Poor drainage, with abundant rainfall.	do	Medium to high, with some low (when drained).	Used in connection with normal soils for pasture or forest (when undrained) and for crops, especially special crops (when drained).
Wiesenboden	Dark-brown or black soil grading, at a depth ranging from 1 to 2 feet, into grayish soil.	Grasses and sedges	Cool to warm, humid to sub-humid.	Poor drainage	Gleization (with some calcification).	High to very high (when drained).	Used in connection with associated normal soils and some for special crops. (Large bodies which are drained have uses similar to Prairie soils.)

It may be said that in a broad sense the differences between individual farms or between agricultural communities within one soil zone are largely quantitative, whereas the distinctions between those in different zones are qualitative. That is, in the Gray-Brown Podzolic region one finds good, bad, and indifferent farms largely of the general-farming type; and in the Chestnut soil region there are good, bad, and indifferent extensive cereal-grain farms. There exists some latitude for qualitative variation, especially in the Gray-Brown Podzolic region, and to a considerable extent in the Podzol, Red, Yellow, Prairie, and Laterite regions, but even in those areas there are definite limits, within which the agricultural enterprise must find expression. In the areas of Chernozem, Chestnut, and Brown soils the limitations are especially strict.

SIGNIFICANCE OF LOCAL SOIL TYPES

These zonal groups of soils represent in general the primary agricultural regions. In many instances the boundaries between the soil groups are sharp, as between the Podzol and Chernozem; in other cases they are less sharp, and there may be a transitional area between the groups, as in the case of the Gray-Brown Podzolic and the Red soils or the Chestnut and the Brown.

Within each of the great zonal groups exist differences in soils of immense importance to the general economic unit adapted to the region as a whole. As an example, the part of a detailed soil map, shown in plate 11, indicates soils within the group, which vary in their adaptability to individual kinds of crops adapted to the region as a whole. The individual detailed soil-survey maps, including usually a county as a unit, are, therefore, primarily concerned with soil differences brought about by local variations of age, parent material, and relief. In some instances, as in the region of the Cascade or Sierra Nevada Mountains, to take an extreme example, great variations in vegetation and climate do obtain within small distances, but usually a detailed soil map has only one, or at the most two, zonal soil profiles. In the example shown the normal soil, Miami loam, occupies the larger portion of the area, while smaller bodies of other soils, having important individual characteristics brought about by local differences in parent material and relief, are present.

The normal Gray-Brown Podzolic soil is represented by Miami loam having a profile described as follows: [15]

A_0. A thin accumulation of litter and forest mold.
A_1. From 0 to 2 inches, dark mellow loam, or humous soil, containing a high percentage of organic matter much decomposed and thoroughly incorporated in the soil. The reaction is medium acid.
A_2. From 2 to 8 inches, light-gray floury loose loam with a high content of silt and slight development of a platy or laminated structure. The material crumbles easily into a structureless mass. The reaction is strongly acid.
B_1. From 8 to 16 inches, light-yellow or grayish-yellow loose friable loam, platy in the upper part, becoming granular below. Very acid.
B_2. From 16 to 36 inches, clay loam breaking into irregular angular particles about one-half inch in diameter. The color of the structure particles is brown, but when they are crushed it is yellowish brown. A thin coating of very fine textured brown material on the structure separates accounts for their brown

[15] MOON, J. W., VEATCH, J. O., WONSER, C. H., and PASCO, R. E.   SOIL SURVEY OF EATON COUNTY, MICHIGAN.   U. S. Bur. Chem. and Soils, ser. 1930, Rept. 10, 46 pp., illus.   1932.

color. When wet the material is sticky, and when dry it is difficult to crush between the fingers. The reaction is acid.

C. Imperfectly weathered pale grayish-yellow calcareous heavy sandy loam or loam till containing a few stones. The material is variable in color, structure, and texture. It is hard when dry.

The Miami loam is developed on the well-drained, undulating upland from glacial till of medium texture, consisting of a mixture of minerals, including a medium amount of calcite. Because of podzolization this soil is not so high in those elements ordinarily considered necessary for plant life as are its poorly drained associates. It is especially productive for the types of trees under which it has developed but less fertile for the crop plants. For these plants the soil is somewhat too acid, too low in organic matter, and somewhat low in plant nutrients, especially nitrogen and phosphorus. These deficiencies can be overcome, however, under good farm management, including the careful planning of rotations with legumes, the use of some lime and phosphatic fertilizers, and the conservation of crop residues and manure.

Associated with Miami loam are a great many local soil types which differ from the normal, owing to some local condition. The profiles of nine of these which are shown on the sample soil map are illustrated in figure 6. It will be noted that two of the soil types, Brookston clay loam and Gilford loam, belong to the intrazonal group of Half-Bog soils and that Rifle peat is a Bog soil. Griffin loam is scarcely a soil at all as it consists of fresh stream alluvium, constantly being renewed by frequent overflows. Genesee fine sandy loam is also developed from stream alluvium, but, as it is older than the Griffin soil and is rarely overflowed, a soil profile is beginning to form. The other soils have profiles approaching that of the Miami and belong with the Gray-Brown Podzolic group of soils, but small differences of significance in local agriculture exist.

As already mentioned, the soils of the Gray-Brown Podzolic group support farming of the general type with some local specialization, especially on the intrazonal soils where they occur in large bodies, such as the Brookston and related Half-Bog soils of the Saginaw River Valley, well-known for the production of sugar beets. Each of the local soil types has its individual crop adaptations within the general group. In many cases soils are found within the general region which are so influenced by local conditions of relief and parent material as to be wholly unfit for crops. Soils on steep hillsides, having a thin solum and subject to excessive erosion when cultivated, very sandy soils, and stony soils are examples of such.

The soil types shown on the sample soil map and illustrated in figure 6 have been rated, comparatively, as to their productivity for the principal crops adapted to the region. These ratings are shown in table 3. The normal soil for the region, Miami loam, has been taken as the standard for each crop. Although the Miami is a soil of medium fertility and responsive to good management, its poorly drained associates have been less leached, are less acid, contain more organic matter, and, when drained, are more productive for several crop plants. Because of variations in parent material, in native vegetation, and in the degree of leaching and other processes attendant to soil formation, the soils vary, one from another in their content of the several plant nutrients and in their acidity. For
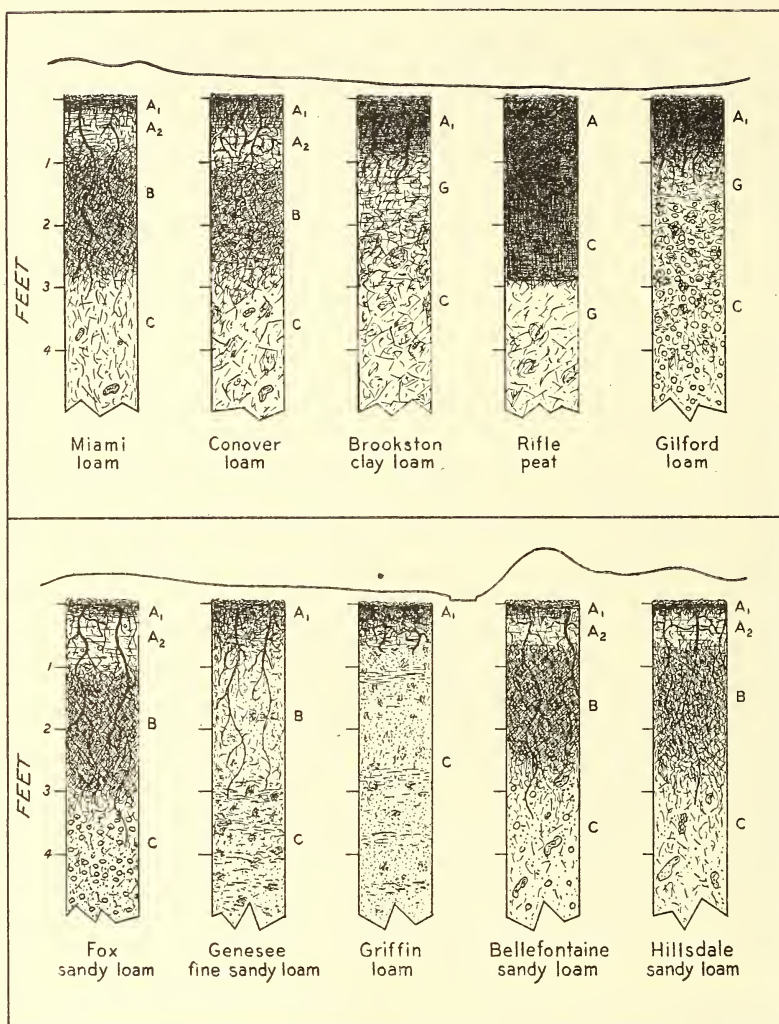
FIGURE 6.—Profiles of several soils found in a small area within the region of Gray-Brown Podzolic soils. Miami loam, developed on the well-drained, undulating upland from glacial till of medium texture and consisting of a mixture of minerals, represents the normally developed soil. The other soils have different profiles because of differences in relief, age, and parent material. Very briefly the important differences may be summarized as follows: Conover loam, imperfect drainage; Brookston clay loam, poor drainage, heavy parent material; Rifle peat, very poor drainage; Gilford loam, poor drainage, coarse parent material; Fox sandy loam, parent material of glacial outwash; Genesee fine sandy loam, young soil developed from stream alluvium; Griffin loam, very young soil from poorly drained stream alluvium; Bellefontaine sandy loam, developed from rolling, light-textured glacial drift; Hillsdale sandy loam, low content of basic minerals in the parent material.

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PLATE 11

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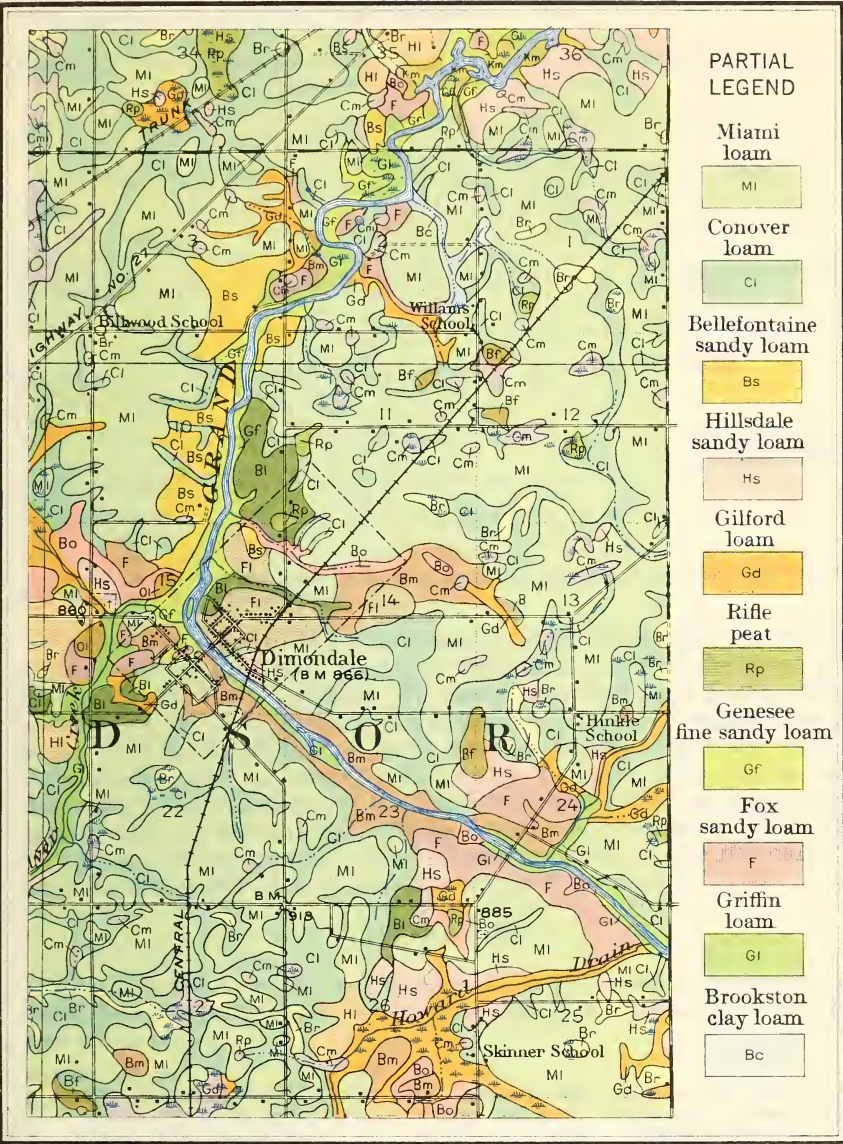
REPRINT OF A SMALL SECTION OF A TYPICAL DETAILED SOIL MAP (EATON COUNTY, MICH.)

Miami loam is a typical Gray-Brown Podzolic soil normal for a large region. Interspersed with the normal soil are areas of other soil types having important characteristics separating them from the normal, such as Conover loam influenced by poor drainage, Hillsdale sandy loam influenced by a high content of siliceous rocks in the parent glacial till, and Griffin loam developed from recent stream alluvium. The area, as a whole, lies well within the Gray-Brown Podzolic region and is adapted to the general type of land use characteristic of that region. Each of the soil units within the area has definite capabilities for use within this general type of use.

example, the Hillsdale soil needs more lime than the Miami, whereas the Bellefontaine usually needs somewhat less, and Brookston none. The Fox is more likely to need some potash in the fertilizer mixture than Miami and several of the others.

TABLE 3.—*Approximate relative productivity of the important local soil types in sample area for the adapted crops* [1]

Soil type	Corn	Wheat	Oats	Barley	Rye	Tame hay	Alfalfa	Vegetables	Small fruits	Potatoes	Sugar beets	Pasture	Apples	Remarks
Miami loam	10	10	10	10	10	10	10	10	10	10	10	10	10	
Conover loam	12	9	12	11	10	12	10	11	8	9	15	14	7	Drainage where needed.
Brookston clay loam.	14	9	12	11	9	14	8	10	3	7	18	16	2	Drained.
Rifle peat	----	----	----	----	----	----	----	----	----	----	----	3	----	Underdrained (could be improved by drainage).
Gilford loam	12	9	12	11	10	12	10	11	5	9	15	14	2	Drained.
Fox sandy loam	8	9	8	8	9	8	8	9	10	10	3	5	8	
Genesee fine sandy loam.	10	9	9	9	9	9	9	10	10	9	6	7	7	
Griffin loam	----	----	----	----	----	3	----	----	----	----	----	8	----	Could be improved by drainage and protection from overflows.
Bellefontaine sandy loam.	7	8	8	8	9	8	8	8	10	9	3	5	8	
Hillsdale sandy loam.	8	9	8	8	9	8	8	8	10	10	5	5	10	

[1] The productivity of the normal soil for the Gray-Brown Podzolic region, Miami loam, under accepted good management, is taken as the standard.

Similar examples of the relationships of the local soil types to the normal soil for the group might be cited in any one of the great soil groups in the United States. In many instances land forms unfavorable for the development of a normal soil, such as rugged mountains, wide sandy plains, or large swampy basins, may cover rather large areas. The important soil, areally, in these cases will be one dominated in its genesis by the local factor of relief or parent material; and the normal soil will be found less frequently, if at all. But even in these extreme cases some conception of the normal soil must form the basis for an understanding of the others.

REFERENCES

The following works are suggested to the reader interested in more detail regarding the distribution, properties, classification, and uses of soils:

GEDROIZ, K. K.
  SOIL ABSORBING COMPLEX AND THE ABSORBED SOIL CATIONS AS A BASIS OF GENETIC SOIL CLASSIFICATION. Transl. by S. A. Waksman. Nossov Agr. Expt. Sta. Paper 38, 29 pp. Leningrad. 1925. [Mimeographed.] (In Papers on Soil Reactions 1912–25.)
GLINKA, K. D.
  THE GREAT SOIL GROUPS OF THE WORLD AND THEIR DEVELOPMENT. Transl. by C. F. Marbut. 235 pp. Ann Arbor, Mich. 1927. [Mimeographed.]
HILGARD, E. W.
  SOILS; THEIR FORMATION, PROPERTIES, COMPOSITION, AND RELATIONS TO CLIMATE AND PLANT GROWTH IN THE HUMID AND ARID REGIONS. 593 pp., illus. New York and London. 1906.
MARBUT, C. F.
  THE RISE, DECLINE, AND REVIVAL OF MALTHUSIANISM IN RELATION TO GEOGRAPHY AND CHARACTER OF SOILS. Ann. Assoc. Amer. Geogr. 15(1): 1–49. 1925.

NEUSTRUEV, S. S.
    GENESIS OF SOILS. Russian Pedol. Invest. 3, Acad. Sci., 98 pp. Leningrad.
        1927.
ROBINSON, G. W.
    SOILS, THEIR ORIGIN, CONSTITUTION, AND CLASSIFICATION ; AN INTRODUCTION
        TO PEDOLOGY. Ed. 2, 442 pp., illus. London and New York. 1936.
RUSSELL, SIR E. J.
    SOIL CONDITIONS AND PLANT GROWTH. Ed. 6, 636 pp., illus. London and
        New York. 1932.
FIRST INTERNATIONAL CONGRESS OF SOIL SCIENCE.
    PROCEEDINGS. 4 v. Washington. 1927.
SECOND INTERNATIONAL CONGRESS OF SOIL SCIENCE.
    PROCEEDINGS. 6 v. Moscow. 1930.
THIRD INTERNATIONAL CONGRESS OF SOIL SCIENCE.
    PROCEEDINGS. 3 v. London. 1935.
UNITED STATES DEPARTMENT OF AGRICULTURE.
    SOIL SURVEY REPORTS, 1899–1935. (About 1,500 separate reports and maps
        have been prepared for various areas in the United States.)
ENCYCLOPEDIA BRITANNICA.
    Ed. 14, v. 19, pp. 688–691, and v. 20, pp. 926–934.

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PLATE 10
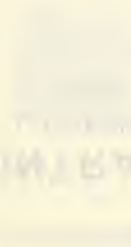
OUTLINE SHOWING THE RELATIONSHIPS AMONG THE IMPORTANT GROUPS OF SOILS

PEDOCALS

PEDALFERS

BASES ACCUMULATE IN ALL OR PART OF THE SOIL PROFILE
(SEMIARID AND ARID REGIONS; GRASS OR DESERT VEGETATION)

BASES DO NOT ACCUMULATE
(HUMID REGIONS)

INTRAZONAL GROUPS
DRAINAGE POOR, AT LEAST A PART OF
THE TIME OR AT SOME EARLY PERIOD

ZONAL GROUPS
DRAINAGE GOOD
BASE EXCHANGE LARGELY SATURATED WITH Ca AND Mg
HORIZONS OF ACCUMULATION OF Ca CO₃ AND Ca SO₄

ZONAL GROUPS
DRAINAGE GOOD

INTRAZONAL GROUPS
I. DRAINAGE POOR
(WITH GLEI FORMATION)
BOG AND MOOR

SOLONCHAK (SALINE SOIL)
HIGH CONTENT OF SOLUBLE SALTS. STRUCTURELESS.
MILDLY ALKALINE. COLLOIDS FLOCCULATED.

CHERNOZEM
BLACK, HIGH IN ORGANIC
MATTER. NUT STRUCTURE.

TUNDRA
COLD ZONE.

BOG SOILS
(FOREST VEGETATION)

ALKALI SOLONCHAKS.
BASE EXCHANGE HAS
MONOVALENT CATIONS,
ESPECIALLY Na.

ALKALINE EARTH SOL-
ONCHAKS. BASE EX-
CHANGE HAS DIVALENT
CATIONS, ESPECIALLY Ca.

DECREASING
ORGANIC MATTER

CHESTNUT SOIL
DARK BROWN. LESS ORGANIC
MATTER THAN IN CHERNOZEM
PRISMATIC STRUCTURE.

INTERMEDIATE

PODZOL
COOL, MOIST CLIMATE.
CONIFEROUS FOREST, LARGELY.
WHITE, PLATY, A₂ HORIZON.
BROWN B HORIZON, OFTEN
CEMENTED TO ORTSTEIN. ACID,
STRONGLY PODZOLIZED.

HALF-BOG SOILS
(FOREST VEGETATION)

IMPROVED
DRAINAGE

IMPROVED
DRAINAGE

**DEGRADED
CHERNOZEM**

BROWN SOIL
BROWN. LESS ORGANIC
MATTER THAN IN CHERNOZEM.
PRISMATIC STRUCTURE.

**GRAY-BROWN PODZOLIC
(FOREST)** MODERATELY COOL
CLIMATE. DECIDUOUS FOREST.
GRAYISH-BROWN A₂ HORIZON.
BROWN B HORIZON. ACID.
STRONGLY PODZOLIZED.

INTERMEDIATE

**GROUND
WATER
PODZOL**

LEADS TO THE
FORMATION OF THE
ZONAL GROUPS FOR
THE AREA.

SOLONETZ (BLACK
PILLARED ALKALI SOIL)
HIGHLY ALKALINE. CON-
TAINS Na₂ CO₃. HARD,
PRISMATIC STRUCTURE.
COLLOIDS DISPERSED.

**SIEROZEM (GRAY
SOIL)**
LOW IN ORGANIC MATTER.

PRAIRIE SOILS
GRASS VEGETATION. VERY
DARK BROWN. MILDLY ACID.
VERY WEAKLY PODZOLIZED.

**RED SOILS (AND TERRA
ROSSA)** MODERATELY WARM
CLIMATE. DECIDUOUS FOREST,
LARGELY. SOME LATERIZATION
AND PODZOLIZATION.

WIESENBODEN
(MEADOW SOILS) (GRASS
VEGETATION)

AND

DESERT SOILS

YELLOW SOILS
MODERATELY WARM CLIMATE.
CONIFEROUS FOREST, LARGELY.
SOME LATERIZATION AND RATHER
STRONG PODZOLIZATION.

II. EXCESS Ca CO₃

LEACHING

AND

SOLOTH LEACHED,
WHITISH, PLATY, A₂
HORIZON OVER A DARKER
B HORIZON. ACID.

**RED SOILS OF TROPICAL
DESERTS**

LATERITE
HOT TROPICAL CLIMATE.
TROPICAL RAIN FOREST,
LARGELY. HIGH CONTENT
OF Al₂ O₃ AND Fe₂ O₃.
STRONG LATERIZATION
FOLLOWED BY PODZOLIZA-
TION.

RENDZINA
BLACK SOILS, GRASS
VEGETATION, LARGELY.
(ALSO SOMETIMES FOUND
IN ASSOCIATION WITH
THE PEDOCALS.)

THE COLORED SECTIONS SHOW THE APPROXIMATE AVERAGE PROFILES FOR THE NORMAL SOILS OF THE GROUPS TO THE DEPTH OF ABOUT 5 FEET.
The details of the profiles of specific soils within each group will vary somewhat from these averages.

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